TRANSACTIONS

of the

American Society for Steel Treating

Vol. VII January, 1925 No. 1

NEW OFFICERS

THE letter ballot cast by the membership of the American Society for Steel Treating was counted by the tellers of election on December 20, 1924. As a result of this ballot the following new officers have been elected: President, W. S. Bidle, president, W. S. Bidle Co., Cleveland; director, F. G. Hughes, vice-president, New Departure Mfg. Co., New Britain, Conn.; director, F. E. McCleary, metallurigst, Dodge Brothers Co., Detroit; director, P. D. Merica, research engineer, International Nickel Co., New York City. W. H. Eisenman, re-elected as secretary.

The board of directors of the Society will be composed of the newly elected officers and the following: Vice-president, R. M. Bird, metallurgist, George F. Pettinos, Inc., Philadelphia; secretary, W. H. Eisenman, 4600 Prospect Ave., Cleveland; treasurer, Zay Jeffries, research bureau, Aluminum Company of America, Cleveland; director, Dr. George K. Burgess, past-president, director, Bureau of Standards, Washington, D. C.; director, J. F. Harper, research engineer, manufacturing department, Allis-Chalmers Manufacturing Co., Milwaukee.

These new elections became effective January 1, 1925.

The report of the tellers of election is as follows:

December 20, 1924.

To the Secretary,
American Society for Steel Treating,
4600 Prospect Avenue,
Cleveland, Ohio.

The Committee of Tellers submits the results of the balloting by the membership for National Officers of the American Society for Steel Treating.

Pursuant to the Constitution of the Society, the Committee of Tellers met at the headquarters of the A. S. S. T. at 4600 Prospect Avenue, Cleveland, on this day and counted the letter ballot cast for National Officers.

The result of the ballot is as follows:

	VOTES
For President—1 year—W. S. Bidle	1428
For Secretary—2 years—W. H. Eisenman	1430
For Director—2 years—F. G. Hughes	1431
For Director—2 years—F. E. McCleary	1424
For Director—1 year—P. D. Merica	1433
Scattering votes—President	8
Secretary	4
Directors	17
Defective votes	23
TOTAL VOTES CAST	1459

Respectfully submitted,

(Signed) L. H. STRANAHAN
D. M. GURNEY
C. G. SHONTZ, Chairman.

WINTER SECTIONAL MEETING

THE Winter Sectional Meeting as announced in the November and December issues of TRANSACTIONS, will be held in Cincinnati under the auspices of the Cincinnati chapter on Thursday and Friday, January 15 and 16, 1925, with headquarters at the Hotel Sinton. This meeting has aroused considerable enthusiasm and no doubt there will be a large attendance of members from the Cincinnati chapter and from other chapters of the Society. The program for this meeting is as follows:

THURSDAY, JANUARY 15

10:30—Registration and Get-together

11:00—Technical session

Gearing as a Medium of Industrial Power Transmission—O. N. Stone, assistant chief engineer, Van Dorn and Dutton Co., Cleveland.

12:00—Luncheon, Hotel Sinton.

2:00 to 5:00 P. M.—Technical session

Sample Preparation for High Power Photomicrography—R. G. Guthrie, metallurgist, industrial gas department, People's Gas Light and Coke Co., Chicago.

Wear and Wear Testing—G. W. Quick and S. J. Rosenberg, Bureau of Standards, Washington.

Corrosion Resisting Steels of the Iron Carbon Chromium and the Iron Carbon Chromium Silicon Series—T. Holland Nelson, metallurgist, United Alloy Steel Corp., Canton, Ohio.

6:45 P. M.—Informal Banquet, Hotel Sinton.

Toastmaster—Julian A. Pollak, vice-president, Pollak Steel Company.

Address of Welcome, Fred A. Geier, president, Cincinnati Milling Machine Company.

Response, W. S. Bidle, president, A. S. S. T.

Impromptu.

Technical paper—*High Tensile Strengths with Low Carbon Steels*—R. H. Smith, vice-president, Lamson and Sessions Co., Kent, Ohio.

FRIDAY, JANUARY 16

Plant Visitation.

Members and guests will assemble at 9:00 a. m. at the Hotel Sinton, where automobiles will be provided for the accommodation of all. The first plant to be visited will be that of the Cincinnati Bickford Tool Company, manufacturers of metal drilling machinery. The second plant will be that of the Cincinnati Milling Machine Company, manufacturers of milling machines and universal cutters and tool grinders.

12:30 P. M.—Luncheon at the Cincinnati Milling Machine Company.

2:00 P. M.—Inspection of the plant of the Rockwood Pottery Company.

3:00 P. M.—Inspection of the plant of the Proctor and Gamble Company.

4:00 P. M.—Annual Automobile Show.

Special arrangements have been made for those who desire to visit the following plants:

American Rolling Mill Company
Ahrens-Fox Fire Engine Company
Andrews Steel Company

Indications at the present time are for a large attendance and all those who can possibly arrange to attend this meeting should do so.

HIGH POWER MAGNIFICATION IN METALLOGRAPHY

By R. G. Guthrie

Abstract

In this paper the author has discussed the subject of high power magnification in metallography rather generally. In his work he has resorted to the use of conical illumination for bringing out maximum detail.

The use of plain axial illumination in taking high power photomicrographs makes it a somewhat easier matter to obtain high power photographs but the contrasts are not as great as with conical illumination.

The conclusions drawn by the author are, that whatever the value inherently contained in high power magnification, their true value is really a matter that will vary from one individual to the other and while there may not have been a great discovery accrue from the use of high power photomicrography, the author has found it to be of great value to him in the examination and interpretation of specimens.

THE subject of high power photomicrography is one upon which opinion has been divided for some time. It seems that the consensus of opinion indicates that there is no more to be seen at 5000 diameters than there is at 1000 diameters. Personally I take exception to this view on the basis that the objectives of the highest power and correction of the present day are capable of resolving more than we can fully comprehend.

A photomicrograph at 500 diameters generally shows beautiful detail and a fineness of general structure. It is, however, analogous to looking at a large gathering of small units from some great distance with the naked eye as compared to looking at the same gathering at a short distance. It is true that you will not see any more units at the shorter distance but the ones you do see will be much more apparent.

There is no doubt in the author's mind but what so-called high power photomicrography is necessary and essential. However, the question arises as to how high the power should be. At this point it must be understood that these photomicrographs, whatever their power, refer to single projection and not to enlarge-

A paper presented before the Spring Sectional Meeting of the Society, Moline, May 22, 1924. The author, R. G. Guthrie, is metallurgist, industrial gas department, People's Gas Light and Coke Co., Chicago.

ments made by photographing a specimen at medium or low power and then enlarging the print or negative with another type of camera.

The practice of photographing the original photomicrograph cannot be accomplished without the attendant loss of a great deal of essential detail. It should be further understood that in the photomicrographs illustrating this paper, that every possible advantage was taken of any means at our command to further enhance their value. Such expedients as the use of so-called conical illumination, ray filters, special attachments and other methods which would give a true representation of the structure, were resorted to. The caption for each photomicrograph contains the data and every possible factor governing the taking and printing in order that the reader may, if in possession of similar equipment, duplicate the results shown.

Equipment Necessary

The equipment necessary for this type of work must be of the highest order obtainable, and a brief statement of the list as used by the author at present and the data accompanying the photomicrographs will be particularly useful and will show what equipment is necessary for the accomplishment of the results in question.

Paper

The paper used in this work was Glossy Velox, the grade depending upon the negative.

Plates

The plates used were Wratten and Wainright's panchromatic "M" plates.

Filters

The filters used were Wratten and Wainright's "M" Filters of "B" grade glass.

Developer

The developer for the paper was Eastman's "MQ" developer, and for the plates it was Pyro Soda developer made from Eastman

chemicals after the formula furnished by Wratten and Wainright for their "M" plates.

Optical Equipment

This equipment was the latest type manufactured by the E. Leitz, Inc., and embodies all the features to be desired for work of this nature. That the method of arriving at the results obtained be better understood, a brief description of this instrument will be useful to the reader at this time. The illuminating system consists of an automatic arc lamp operated on direct current and having a vertical and a horizontal adjustment. The condenser system consists of two lenses mounted in a horizontally adjusted barrel on the arc lamp stand. The next condenser system is made up of a stationary two-lens condenser mounted behind a vertical adjustable iris-diaphragm which has a barrel for holding the stops as used in conical illumination. This latter assembly has a rack and pinion adjustment. The third condenser has an iris-diaphragm in front of it also. This latter condenser is of the one-lens type and has a focusing adjustment in the form of a lever in a spiral slot which enables the operator to focus the light on the vertical illuminator.

The illuminator stem carries both the plain glass and prism type illuminator and a choice of either may be had by moving the stem in or out as the case may be. Probably the most important feature which is a departure from the conventional type of apparatus is the focusing mechanism. The coarse focusing adjustment naturally acts upon the stage and is composed of a rack and pinion mounted in the center of two large "V" ways provided with a locking device. The fine, focusing adjustment, however, is on the objective proper and not merely a vernier on the coarse adjustment. This fine focusing attachment has a great many advantages over the former type in that the weight on it is a constant and is not affected in any way by the weight of the stage or specimen which may be securely locked after the coarse adjustment is made. The camera is of the conventional type with the exception of a periscope arrangement which enables the operator to focus on the back glass without moving from his position at the microscope, thereby enabling him to make any adjustments of the arc lamp or illuminators, as well as the position of the

sample on the stage directly upon the position of the plate.

The final focusing, however, is accomplished with a plane glass screen and magnifier. It might be well to mention that in the author's opinion the more adjustments contained on an apparatus of this kind the better, especially on this class of work. This fact will at once be apparent to any one attempting to duplicate these results.

It is becoming more necessary each day that the magnification figures, as given in various publications, carry such data with them as will conclusively prove just how they were obtained. A magnification of 500 diameters may be arrived at by using a 4-millimeter objective with an ocular having an initial magnification of 2.6 and a 1000-millimeter camera bellows extension, or it may be arrived at by using a 2-millimeter oil immersion objective with the same ocular but having only a 450-millimeter camera bellows extension, or it may be further arrived at with a 2.2-millimeter objective using the same ocular and a 500-millimeter camera bellows extension, or it may be arrived at by using a 4-millimeter objective with a 6-diameter ocular and a camera bellows extension of 500 millimeters. Still further, it may be obtained by using an 8-millimeter objective with a 10-diameter ocular and a camera bellows extension of 500 millimeters.

Obviously, something should be done to determine just what 500 diameters really does mean. It cannot be taken for granted that every metallographer will follow the principal of using the highest power objective together with the lowest power ocular and camera bellows extension for a given magnification because that would mean that practically all photomicrographs above 350-400 diameters would be taken with a 2-millimeter oil immersion objective. In fact there are so many ways to obtain a magnification of this power that it would be a very foolish thing to try to name all of them. Likewise it is entirely possible to take a photomicrograph of 2000 diameters in any one of 5 or 6 different ways, using 3 or 4 different sizes of objectives.

The resolving power, expressed many times as the number of lines per lineal inch which a given objective will resolve, is due primarily to the wave length of light used, as well as the numerical aperture of the objective. The formula expressing the distance

between two lines, which can just be resolved, is

$$D = \frac{1}{2} \frac{w.l}{N.A}$$

which means that the shorter the wave length of light, the greater the resolving power for a given objective. Thus, using an objective having a numerical aperture of 1.40 and another objective having a numerical aperture of 0.95, and both objectives working under the same wave length of light, it will be obvious that the objective having a numerical aperture of 1.40 will be capable of resolving structures that the objective having the numerical aperture of 0.95 will show as a solid mass. It is common practice to designate the objective by its focal length and to neglect to state whether it is achromatic, fluorite, or apochromatic, which fact makes a great deal of difference to the ultimate resolving power of the objective. For instance, a 2.2-millimeter focal length objective of the fluorite type will have a numerical aperture of only 0.8, whereas an apochromatic objective of 2 millimeters focal length will have a numerical aperture of 1.40, which is the highest numerical aperture obtainable.

It is generally true that the greater the focal length, the less the numerical aperture, but where the fluorite objective of 2.2-millimeter focal length has only a numerical aperture of 0.87, the 4-millimeter apochromatic objective, which is almost twice the focal length of the fluorite objective, has a numerical aperture of 0.95 and, consequently, is of much greater resolving power.

The photomicrograph of Fig. 1 shows a mass that is not resolvable by the objective used, whereas Fig. 2 at the same magnification does resolve the constituents. In both instances, the same wave length of light was used. Fig. 3 is identical with Fig. 2 and shows the same field under conical illumination.

In presenting these photomicrographs an attempt has been made to produce them at various magnifications, showing the effect of illuminating systems, etc., which will better bring out the full efficiency of the objective, as well as to show the effect of high magnification.

Practically all of the remainder of the photomicrographs, with the exception of two, are taken with the view of bringing out the highest efficiency of the highest power objective obtainable.

Fig. 1—Carburized Abnormal Steel. Magnification 1000 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten B.
CONICAL STOP NO: None.
1ST IRIS: 16½
2ND IRIS: ½
RACK POSITION: 0
ILLUMINATOR FOCUS: center.
OBJECTIVE: 14-millimeter achromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Pl Axial.
CAMERA EXTENSION: 61½ centimeters.
EXPOSURE TIME: 2¼ minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph shows a field, the details of which were not resolved by the objective used.

Fig. 2—Carburized Abnormal Steel. Magnification 1000 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten B.
CONICAL STOP NO: None.
1ST IRIS: 16½
2ND IRIS: ½
RACK POSITION: 0
ILLUMINATOR FOCUS: center.
OBJECTIVE: 3-millimeter apochromat.
OCULAR: 8 x Periplan.
TYPE ILLUMINATION: Pl Axial.
CAMERA EXTENSION: 44 centimeters.
EXPOSURE TIME: 40 seconds.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph shows a field of the same specimen as Fig. 1, using the same wave-length of light and the same magnification. In this case the details of the structure were resolved by the objective.

namely, an oil immersion apochromatic objective of a 2-millimeter focal length and 1.40 numerical aperture. The steel photographed is a sample taken from a carburized bar of so-called abnormal steel, the abnormality being most apparent in the outer edges of the case where the excess cementite is in curled or broken masses, having no definite or continuous configuration. It will be evident that in a great many instances the cementite will be present in a ferrite matrix from which a practically complete divorce of the pearlite has been accomplished. For further interpretation, the author would recommend that the reader peruse the excellent paper by E. W. Ehn, published in the September, 1922, issue of TRANSACTIONS, in which Mr. Ehn has brought to light and explained a condition in steels, named by him as abnormal steel, which has no doubt caused a great deal of trouble ordinarily attributed to other causes.

The conditions under which Fig. 4 was taken, with the exception of the objective, were identical with those of Fig. 3, but in this instance a 2-millimeter, 1.40 numerical aperture apochromatic, oil immersion objective, was used which gives a magnification of 1500 x. Increased magnification in this instance is not so great when it is considered that the magnification of Figs. 1, 2 and 3 is 1000 diameters, but the increase in resolving power is readily apparent, inasmuch as the objective in this instance is the highest power obtainable.

The rest of the photomicrographs were all made using this objective, and the reader may readily judge for himself as to just how high an enlargement may be before it ceases to be useful.

Fig. 5 is identical with Fig. 4, with the exception that the ocular has been increased to 12 power. Fig. 6 is identical with Fig. 5, but the ocular in this instance has been increased to 25 power with a consequent measured magnification of 5000 x diameters and 2000 x diameters respectively. Fig. 7 was taken under the same conditions as Figs. 4, 5 and 6, but in this instance it was desired to obtain a photograph as near the actual resolving power and magnification of the objective as possible, with the result that it was enlarged only with a 4-diameter periplan ocular and 19.25-centimeter camera extension. Fig. 8 was taken with the 2-millimeter 1.40 numerical aperture oil immersion objective with a 44-centimeter camera bellows extension and an 8-power ocular,

Fig. 3—Carburized Abnormal Steel. Magnification 1000 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten B.
CONICAL STOP NO: None.
1ST IRIS: 15
2ND IRIS: ⅔ open.
RACK POSITION: 1¼ millimeters up.
ILLUMINATOR FOCUS: center.
OBJECTIVE: 3-millimeter apochromat.
OCULAR: 8 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 44 centimeters.
EXPOSURE TIME: 2 minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph is the same as Fig. 2 excepting that conical illuminaiton was used. The direction of the light was from the upper left hand corner toward the lower right hand corner.

Fig. 4—Carburized Abnormal Steel. Magnification 1500 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten C.
CONICAL STOP NO: None.
1ST IRIS: 15
2ND IRIS: ⅔ open.
RACK POSITION: 1¼ millimeters up.
ILLUMINATOR FOCUS: center.
OBJECTIVE: 2-millimeter, oil immersion 1.40 N. A.
OCULAR: 8 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 44 centimeters.
EXPOSURE TIME: 2½ minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

The condition under which this photomicrograph was taken, with the exception of the objective, were identical with that of Fig. 3. The increase in resolving power is readily apparent, inasmuch as the objective in this instance is the highest power obtainable. The direction of the light was from the upper right hand corner toward the lower left hand corner.

Fig. 5—Carburized Abnormal Steel. Magnification 2000 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten C.
CONICAL STOP NO: None.
1ST IRIS: 15
2ND IRIS: ⅔ open.
RACK POSITION: 1¼ millimeters up.
ILLUMINATOR FOCUS: center.
OBJECTIVE: 2-millimeter, oil immersion 1.40 N. A.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 44 centimeters.
EXPOSURE TIME: 4½ minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph was taken under exactly the same conditions as those of Fig. 4 except for the increase in magnification due to the use of a higher power ocular. The direction of the light was from the upper right hand corner toward the lower left hand corner.

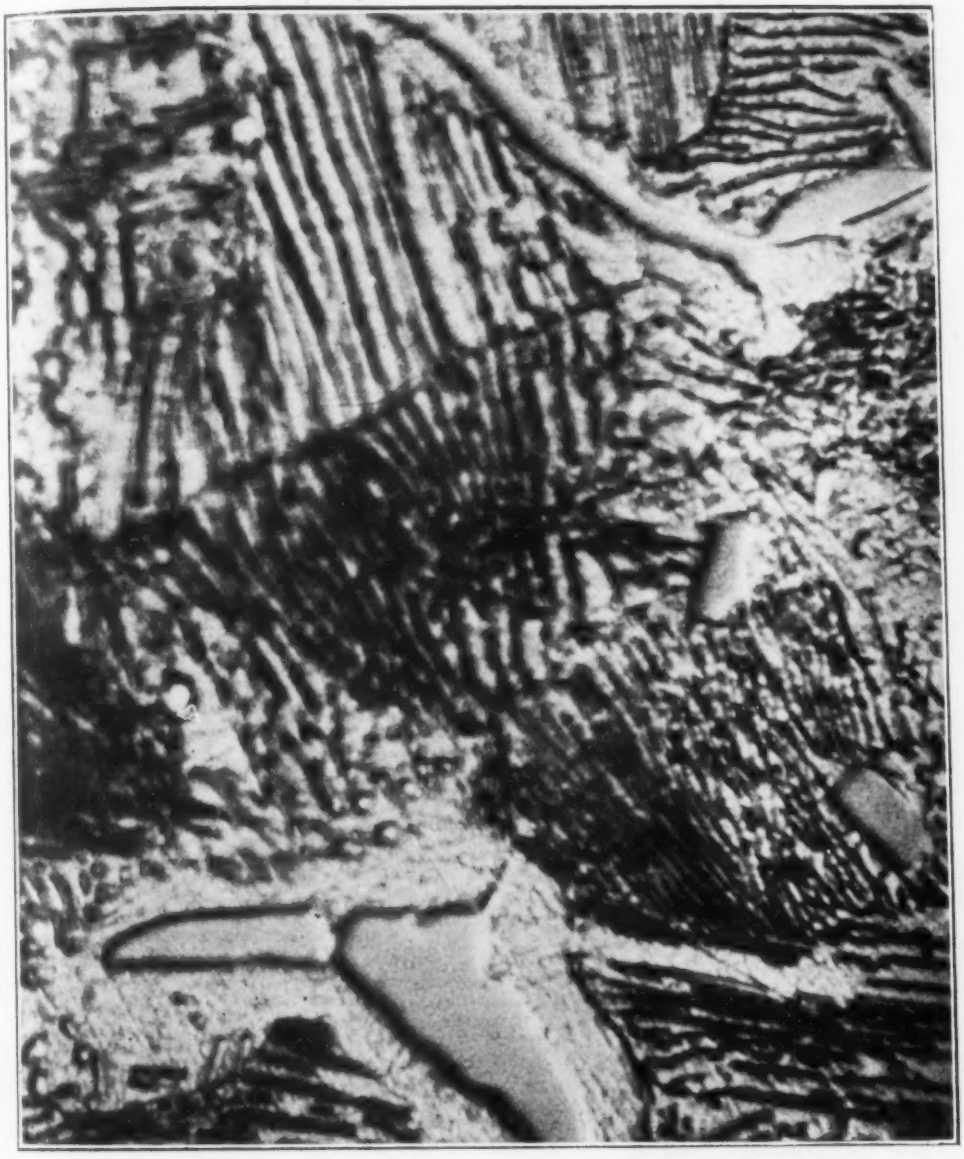


Fig. 6—Carburized Abnormal Steel. Magnification 5000 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes
ILLUMINATION: Arc.
FILTER: Wratten C.
CONICAL STOP NO: None.
1ST IRIS: 15
2ND IRIS: ⅔ open.
RACK POSITION: 1¼ millimeters up.
ILLUMINATOR FOCUS: center.
OBJECTIVE: 2-millimeter, oil immersion 1.40 N. A.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 44 centimeters.
EXPOSURE TIME: 20 minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph was taken under exactly the same conditions as those of Fig. 5 except for the increase in magnification due to the use of a higher power ocular. The direction of the light was from the right to the left.

which gives the same magnification as Fig. 4, but in this instance extreme conical illumination was used by inserting conical stop No. 5 and moving the position of the rack 7 millimeters down

Fig. 7—Carburized Abnormal Steel. Magnification 350 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten C.
CONICAL STOP NO: None.
1ST IRIS: 15
2ND IRIS: ⅔ open.
RACK POSITION: 1¼ millimeters up.
ILLUMINATOR FOCUS: center.
OBJECTIVE: 2-millimeter, oil immersion 1.40 N. A.
OCULAR: 4 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 19¼ centimeters.
EXPOSURE TIME: 45 seconds.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph was taken under the same conditions as those of Figs. 4, 5 and 6, but in this instance it was desired to obtain a photograph as near the actual resolving power and magnification of the objective as possible, with the result that it was enlarged only with a 4-diameter periplan ocular and 19.25-centimeter bellows extension.

from its normal position. The field in this instance shows pearlite in a ferrite matrix in the core of the same sample used for the other photomicrographs.

Fig. 9 shows a condition of the case in which free cementite in the form of little needles or sticks seem imbedded in a ferrite matrix. The magnification of this photograph is 3800 diameters and in this instance a 12-power ocular with an 80-centimeter camera bellows extension was used.

Fig. 10 shows a very peculiar effect in that the small grain in the center appears to be below the surface in one position, and when turned upside down appears to be above the surface. This plate was obtained by using conical, polarized illumination and

Fig. 8—Carburized Abnormal Steel. Magnification 1000 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten C.
CONICAL STOP NO: 5
1ST IRIS: 7½
2ND IRIS: ⅔ closed.
RACK POSITION: 7 millimeters down.
ILLUMINATOR FOCUS: ¼ down.
OBJECTIVE: 2-millimeter, oil immersion 1.40 N. A.
OCULAR: 8 x Periplan.
TYPE ILLUMINATION: Extreme Conical.
CAMERA EXTENSION: 44 centimeters.
EXPOSURE TIME: 10 minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

In this photomicrograph extreme conical illumination was obtained by using the conical stop and by adjusting the position of the rack. The direction of the light was from the left to the right.

Fig. 9—Carburized Abnormal Steel. Magnification 3800 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten C.
CONICAL STOP No.: 5
1ST IRIS: 7½
2ND IRIS: ⅔ closed.
RACK POSITION: 7 millimeters down.
OBJECTIVE: 2-millimeter oil immersion 1.40 N. A.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Extreme Conical.
CAMERA EXTENSION: 80 centimeters.
EXPOSURE TIME: 14 minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 4 minutes.

This photomicrograph is of an abnormal steel carburized showing free cementite in the form of needles or sticks imbedded in a ferrite matrix. The direction of the light was from right to left.

Fig. 10—Carburized Steel,—Core. Magnification 725 x.

ETCH: 2 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: None.
CONICAL STOP NO: None.
1ST IRIS 15½
2ND IRIS: closed.
RACK POSITION: center.
ILLUMINATOR FOCUS: center.
OBJECTIVE: 3-millimeter apochromat.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Polarized.
CAMERA EXTENSION: 21¼ centimeters.
EXPOSURE TIME: 8 minutes.
POLARIZER POSITION: crossed.
ANALIZER POSITION: 280 degrees.
PLATE: Wratten M.
SIZE: 4x5 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph shows a very peculiar effect in that the small grain in the center appears to be below the surface in one position, and when turned upside down appears to be above the surface. This photomicrograph was obtained by using conical, polarized illumination.

the very light areas in this instance are pearlitic. It might be well to state at this time, although beside the subject, that under crossed nicols the pearlite areas in a piece of material in which there is an excess of ferrite invariably show as bright, starlike masses, whereas the ferrite matrix is almost entirely black. However, when oxide spots, non-metallic inclusions, etc., are present,

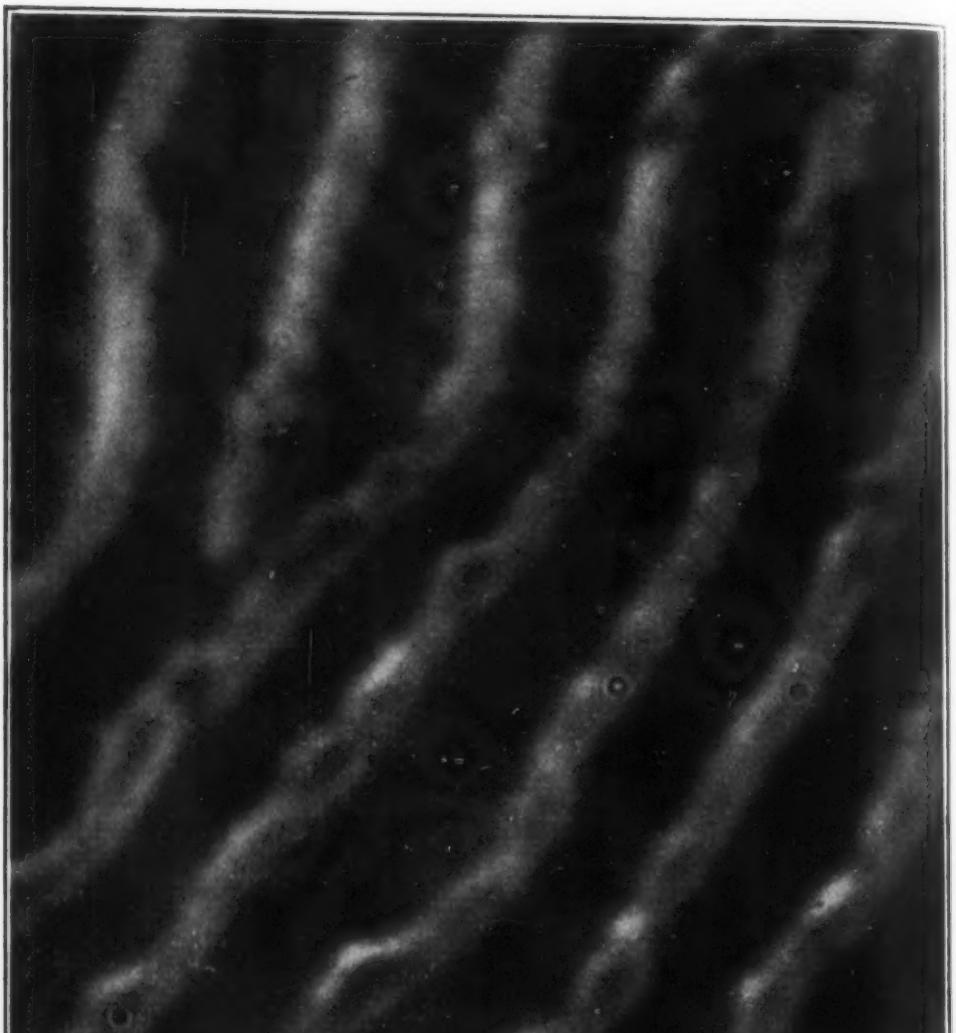


Fig. 11—Carburized Steel. Magnification 12,500 x.

ETCH: 7 seconds in 2% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten B.
CONICAL STOP NO: 5
1ST IRIS: 9
2ND IRIS: ½
RACK POSITION: 0
ILLUMINATOR FOCUS: center.
OBJECTIVE: 2-millimeter, oil immersion 1.40 N. A.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 111.6 centimeters.
EXPOSURE TIME: 1 hour, 15 minutes.
PLATE: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 3 minutes.

This photomicrograph is in so far as is known the highest power ever obtained by single projection direct from the objective. The arc lamp carbons had to be changed once at the end of the first 20 minutes which in no way interfered with the results. The vibration absorbers were used, and those present moved freely about the room without affecting the focus or ultimate results. It took one hour to satisfactorily focus this photograph. The photomicrograph is of lamellar pearlite in a piece of abnormal steel carburized and heat-treated.

they as a general rule will also show black with the ferrite when the nicols are crossed.

In Fig. 11 it was desired to get the maximum detail and contrast at the highest power enlargements, and the ultimate enlargement is 12,500 diameters made under the conditions shown in the caption.

That which actually constitutes the limit of magnification within certain ranges, becomes a matter of personal opinion, and as far as the actual value of the photomicrograph is concerned, there seems to be a pretty fair limit to the extent to which the image of a given objective should be enlarged. Although this limit varies with various structures, at present it rests with the metallographist to use his own discretion. If pressed for a definite figure the author would say 4000 or 5000 x with an objective having 1.40 numerical aperture.

It is no doubt true that when an image is enlarged sufficiently to see all the detail present that further enlargement does not show any more detail than there was in the first instance, but in the ordinary field at low magnification, there are so many details of structure to be taken into consideration that all of us no doubt are lacking the fundamental information relating thereto. On the other hand, when these same fields are taken a little at a time and enlarged to a point where all their details are readily apparent, it is not likely that the interpretation will be confused, and it is the author's prediction that eventually it will be the practice of metallographists generally to examine all their samples, particularly the pearlites, first, at a low resolving power to get the perspective of the general structure of the piece in question, and second, at the higher powers to get specific information regarding certain areas, and third, resort to extreme magnification or enlargement of certain portions of these areas for his ultimate information regarding the material. An instance of this, which is of no great particular importance at the present, is shown in Fig. 8, in which the ferrite grain boundary in the center is apparently distinctly above the grain it surrounds, whereas at low magnification or a low factor of enlargement, this condition is not readily apparent. However, upon turning this plate upside down and closing one's eyes for a moment, the reverse condition is apparent. This

latter condition is the true condition of the sample and the former only an illusion.

Whatever the value inherently contained in high magnification may be, its true value is really a matter that will vary from one individual to another and cannot be set down at the present time as having had any great discoveries result from it. Personally, the author considers it of a great deal of value to him in the examination and interpretation of samples.

FUSED SALT BATHS FOR THE PREVENTION OF SOFT SPOTS IN QUENCHED HIGH CARBON AND CARBURIZED STEELS

By W. J. Merten

Abstract

Irregularity of surface hardness on high carbon tool steels and carburized steels heated in fused salt baths and quenched in the ordinary quenching liquids such as water, oil, brine, etc., has been the subject of a number of papers in recent years. In nearly all of these papers there is a lack of conviction as to the usefulness of the salt bath for the heating of steels prior to hardening and consequently there has been a lack of enthusiasm in their adoption.

The experiments described in this paper give evidence for the cause of the major objections to salt bath heating and describes the manner in which these unsatisfactory conditions can be eliminated. The composition of the quenching medium used to prevent soft spots is disclosed and discussed in detail.

Introduction

EVENTS leading up to this development—tests conducted for the approval of suppliers of a one per cent plain carbon tool steel showed a series of hardened plug gauges about 2 inches in diameter made of the different samples of this steel, to have spots which were soft to the file. These spots occurred on practically all steels submitted. They were, however, more conspicuous on some steels than on others. They were more numerous when the same steel was heated in a salt bath than when heated in the gas-fired furnace, but they occurred regardless of which type of heating apparatus was used. Microscopical examination of these specimens revealed areas having a soft troostitic structure adjacent to hard martensitic patches. The locations of these soft spots could be changed from one position to another on rehardening, so that a soft spot on rehardening might be hard, and a hard spot might change to a soft one. It was found that decarburization did not

A paper presented before the Boston Convention of the Society, September, 1924. The author, W. J. Merten, is metallurgical engineer with the Westinghouse Electric and Manufacturing Company, Pittsburgh.

account for this phenomenon entirely. The penetration of this difference in hardness was appreciable and would occur in steels of the cleanest and highest grade, so that the possibility of a concentration of metalloids did not offer an explanation of the trouble.

The various quenching liquids, water, concentrated sodium chloride solutions, sulphuric acid, agitated or still, gave the same result, as far as could be judged by ordinary hardness tests. All gave irregular surface hardness.

It was while working with some finish-machined carburized cam shafts which showed this irregular hardened condition that the real cause of the occurrence of soft spots was detected. These shafts showed bluish colored areas after being hardened in a salt solution of water, or even when quenched in sulphuric acid, indicating that oxidation was occurring during quenching. Microscopic, macroscopic and fracture examinations were made of these shafts after quenching, but these tests revealed nothing unusual except a troostitic rather than a martensitic structure in the bluish areas. The oxidation was superficial and was removed entirely by ordinary polishing methods. It was quite evident that all of this trouble had occurred during quenching rather than during heating, and consequently a study of quenching liquids, their characteristics and behavior in contact with red hot steel coated with fused salt, was made. These tests lead to a satisfactory explanation and subsequent elimination of non-uniform surface hardness.

Cause of Soft Spots

It has been universally recognized that heat abstraction by the quenching liquid, or heat transfer from the red hot steel to the quenching liquid, is materially retarded by vapor films forming on the surface of the steel when immersed in the liquid. Agitating and circulating schemes have been resorted to, for the prevention of the vapor films, but these methods are only partially successful in preventing irregular hardening. In order to produce extreme hardness uniformly in one per cent carbon steels, the usual agitation or circulation is not sufficient to entirely remove these gas films, and troostitic areas are persistently produced. We have found this to be equally true with steels containing up to 0.75 chromium, small percentages of tungsten, and manganese in excess of 1.00 per cent.

Obviously, it is almost impossible to direct the flow of the

quenching liquid so as to prevent still or stagnant pockets over certain areas on the surface of the piece of steel. Adhering salt films must be dissolved before maximum quenching can be obtained.

Elimination of Soft Spots

The problem therefore resolved itself into finding a quenching liquid which would quickly dissolve the film of the sodium-potassium chloride salt mixture, cool drastically, have a low vapor pressure and not be easily vaporized. Naturally brine was the base of this quenching liquid since we were aware, that heat abstraction is materially aided by sodium chloride additions to water, up to the point of saturation.* The value of lime added to brine for the purpose of raising the boiling point of the brine is also common knowledge, and the suppression of the formation of gas films can be relied upon as a result of this lime addition. In view of the fact that a mixture of sodium cyanide and sodium chloride is a very effective solvent for chlorides, a quenching bath containing a mixture of the three constituents, sodium chloride, sodium cyanide and lime, was made up for experimental work. This bath consisted of 300 gallons of water containing 150 pounds of sodium chloride, 100 pounds of lime, and 75 pounds of sodium cyanide. When properly agitated to keep the ingredients in suspension it dissolved the adhering salt film from the steel instantaneously and prevented the formation of a vapor or gas film, as well as, cooling the steel rapidly. The results of these tests were very gratifying. A glass hard surface was produced free from soft spots. The depth of complete hardness, or martensitic structure, was increased materially, and fine acicular martensitic markings extended deeply into the specimens. Cooling curves of two different steels treated in this bath are reproduced and illustrated in Figs. 1, 2 and 3, which also show a comparison of quenching speed with other liquids. The specimen used was a cylinder 1⅜ inches in diameter and 3 inches long, having a small hole drilled to the center, into which the fire end of a pyrometer was inserted.

The outstanding features of this quenching bath are: (1) its composition; (2) its remarkable speed and uniformity of heat abstraction; and (3) that it does not cause cracks, hair lines, or any other surface defects or internal ruptures on tools and steel

*Lynch & Pilling, Cooling Properties of Technical Quenching Liquids, A. I. M. M. E., Vol. 62, 1920, p. 665.

parts of intricate design. Non-uniform cooling rather than drastic cooling is the cause of most tool breakage during heat treating operations.

An anlysis of the conditions and factors causing volumetric changes during the cooling of steel and results obtained on samples, as well as in routine production, shows that cracking occurs

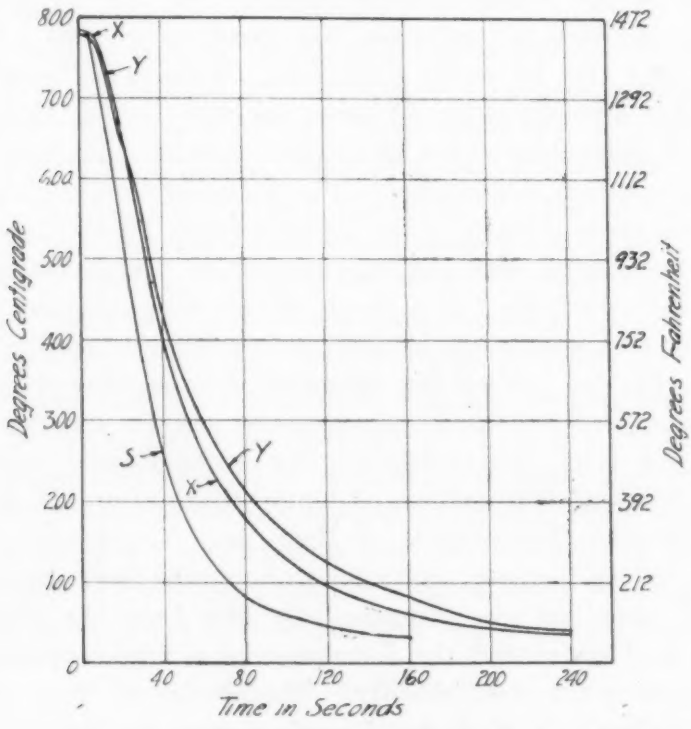


Fig. 1—Quenching Curves for a 1.00 Per Cent Carbon Steel when Quenched in Oil and Salt, Lime, Cyanide Solution. X and Y are Different Brands of Quenching Oils and S is the Salt, Lime, Cyanide Solution. Test Piece Dimensions, 1⅜x1⅝x3 inches.

when irregular cooling produces a dense structural condition (troostitic) in part of the steel and a less dense condition (martensitic) in another part. The excessive straining induced in the less dense martensitic areas, which are unstable and ready to change to the more stable and dense troostitic form, renders the tool subject to checking when heated locally, as by grinding. Such local heating frequently produces hairline cracks.

The surface of the steel quenched in this bath retains its lustre to a remarkable degree due to the protection of the adhering film of lime. The probable reactions involved in the dissolving of the

salt film in the quenching bath upon immersion of the hot salt-coated steel are as follows:

(1) $H_2O + 2\,NaCl + Ca(OH)_2 + NaCN = CaCl_2 + 2\,NaOH + NaCN + H_2O$

(2) $CaCl_2 + 2\,NaOH + NaCN = Ca(OH)_2 + 2\,NaCl + NaCN + H_2O$

The bath of an aqueous solution of salt, lime and sodium cyanide ($H_2O + NaCl + Ca(OH)_2 + NaCN$) dissolves the film of

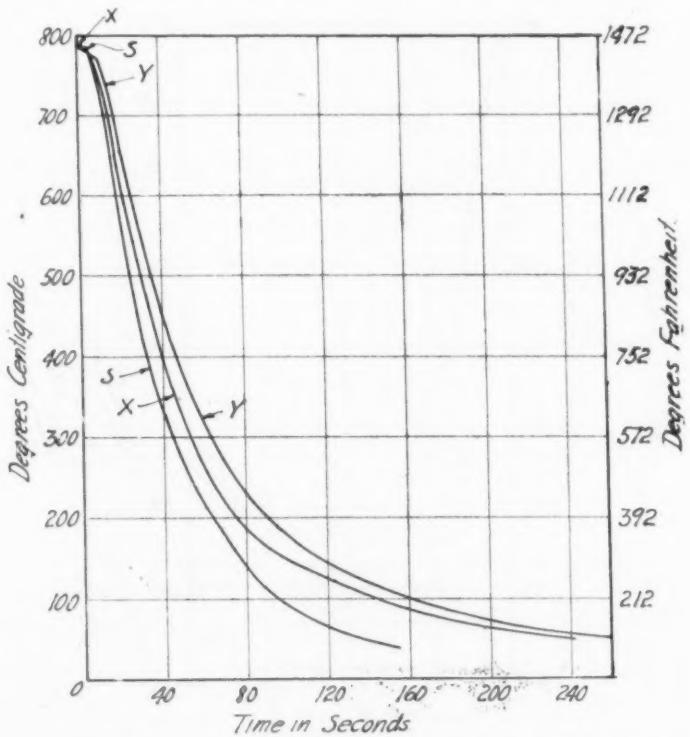


Fig. 2—Quenching Curves for a Non-Shrinking Steel when Quenched in Oil and Salt, Lime, Cyanide Solution. X and Y are Different Brands of Quenching Oils and S is the Salt, Lime, Cyanide Solution. Test Piece Dimensions, 1⅜x1⅝x3 inches.

sodium-potassium chloride clinging to the red hot steel forming; — (1) $CaCl_2 + NaOH + NaCN$, because the calcium reaction energy is greater at this temperature than that of the sodium, and will draw chlorine away from the sodium which in turn hydrolyzes water. The well-known reaction diagram shown in Fig. 4 is a graphical illustration of this change in reactive energy of sodium and calcium chlorides at higher temperatures. As the temperature

falls (Ca O Cl) + Na Cl is formed again, sodium regaining its lost predominance in reaction energy. The function of the colloidal lime in suspension is to prevent vapor packing or concentration.

Purification of Fused Salt Bath Consisting of a 50 Per Cent Mixture of Sodium and Potassium Chlorides

The useful temperature range of this bath is shown in Figs. 5, 6 and 7. The purification of a fused salt bath composed of equal parts of sodium and potassium chlorides may be accom-

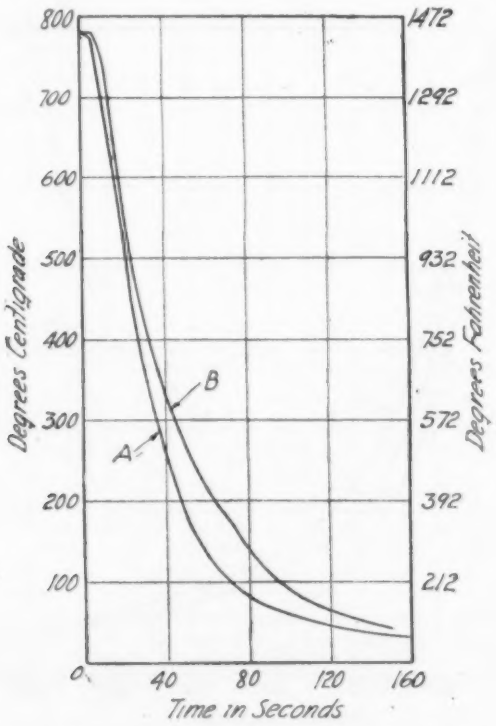


Fig. 3—Quenching Curves for a 1.00 Per Cent Carbon Steel and a Non-Shrinking Steel when Quenched in the Salt, Lime, Cyanide Solution. A is the Carbon Steel and B is the Non-Shrinking Steel. Test Piece Dimensions, 1⅝x1⅝x3 inches.

plished by adding boric acid and charcoal to the fused salt. This combination forms, after completing its reaction, a viscous glassy slag on top of the bath, emitting a strong odor of carbon bisulphide, indicating the removal of sulphur which was probably present as potassium and sodium sulphate. The addition of small amounts of calcium carbonate seems to increase this reaction. In the experimental work conducted by the author frequent addi-

tions of small amounts of boric acid with a little charcoal have been the only purifying agents employed on this salt bath and for an 8-months period no decarburization of any of the tool steels

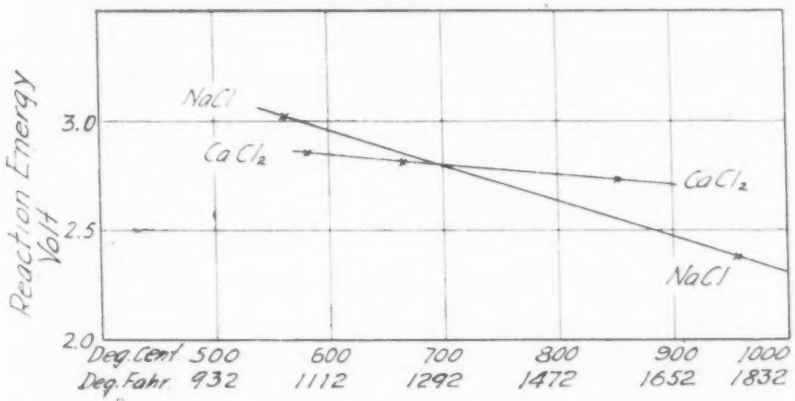


Fig. 4—Reaction Energy Diagram of Sodium Chloride and Calcium Chloride at the Higher Temperatures.

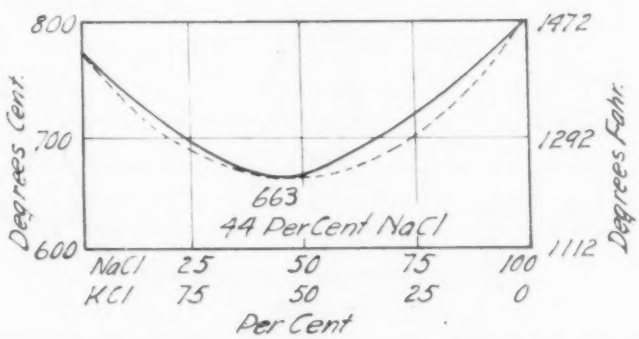


Fig. 5—Melting Point Curve for Sodium and Potassium Chloride Mixtures. (Landolt-Börnstein.)

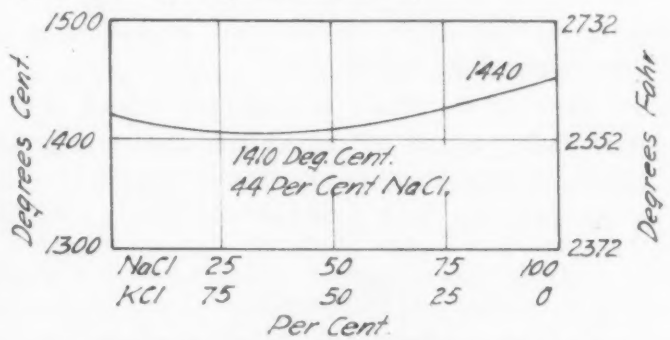


Fig. 6—Boiling Point Curve for Sodium and Potassium Chloride Mixtures. (Landolt-Börnstein.)

or carburized steels treated has been observed. In fact, all pitting which was formerly of more or less general occurrence has not been encountered with this salt bath.

Containers

A container which has given excellent service considering its cost is a 3/8 inch thick boiler plate pot having electrically welded seams and alloyed with aluminum by dipping the container into a molten bath of aluminum. Avoidance of direct impingement of

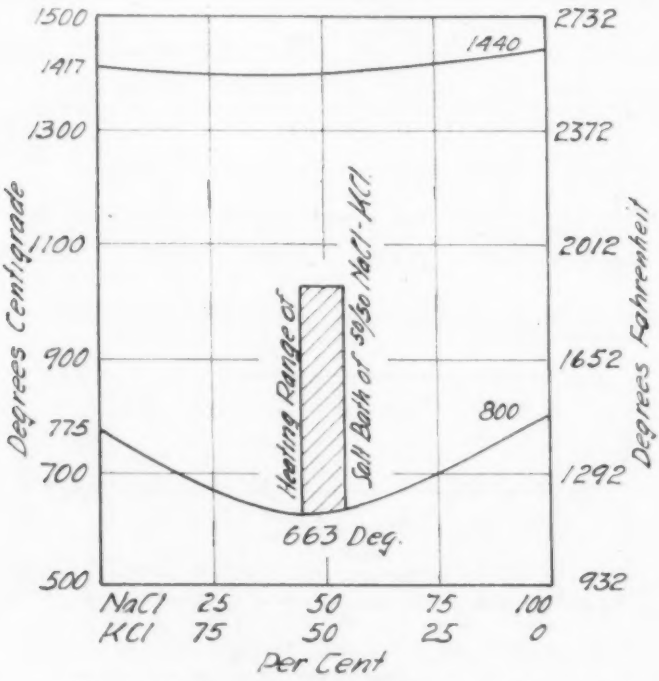


Fig. 7—Melting and Boiling Point Curves for Sodium and Potassium Chloride Mixtures.

flame from the burner must be observed, to obtain a life of from 500-600 intermittent heat hours.

The other type of container is a higher priced cast pot having good qualities, being made of an aluminum-iron-chromium-nickel alloy. Intermittent service introducing expansion and contraction strains are detrimental, and shorten the life of these cast containers.

Summary

As a result of the data obtained and presented in this paper, the following conclusions are reached:

1. Uniform and extreme surface hardness of high carbon and carburized steel depends upon uniform and accelerated abstraction of heat.

2. Vapor and salt films are poor conductors of heat and wherever present, they prevent drastic cooling and consequently cause irregular hardness of the steel over areas where these films occur.

3. Ordinary quenching liquids do not rapidly dissolve the salt films which form from the sodium and potassium chloride heating bath. They seem to promote, rather than prevent, the formation of gas films at the surface of the steel under treatment.

4. A quenching medium of the composition given in this paper solves the problem of uniformly producing a fully hardened steel when heated for hardening in fused salt baths, the resultant structure being entirely martensitic.

5. When a fused salt bath is purified with boric acid and charcoal, this purification is maintained by small additions from time to time of this scavenging mixture, high carbon tool steel will not decarburize, neither will carburized steel be pitted, nor will other objectionable surface conditions prevail.

6. The containers mentioned and successfully employed for this fused salt heating bath, suggest a definite line of development for containers and seems to indicate that low carbon steel plates properly coated with highly resistant alloys of an aluminum base, would serve satisfactorily for this class of steel heating.

Discussion of Mr. Merten's Paper

CHAIRMAN D'ARCAMBAL: In opening the discussion of Mr. Merten's paper, I would like to ask Mr. Merten if he believed he would have obtained decarburization if he had quenched into a brine solution?

W. J. MERTEN: We did obtain the oxidized film, which showed plainly that we had an oxidizing effect; while it was only superficial, nevertheless it was there.

W. A. MUDGE: I would like to ask Mr. Merten if he would care to state the completeness of the removal of sulphur by the charcoal-boric acid mixture.

W. J. MERTEN: We put a handful of boric acid and charcoal on the top of the bath, and while the bath was cloudy and entirely opaque, entire clearing of the muddiness was accomplished in about a half minute's time. We did not, however, make a quantitative check on the amount of sulphur removed. It is the sulphur that causes pitting, but no such action was noticed, and I believe the amount of sulphur left was so small that it is difficult to check it.

CHAIRMAN D'ARCAMBAL: Is it necessary to heat up this mixture of sodium-potassium chloride to 1600 or 1700 degrees Fahr. and cool it down and heat it up again, repeating this heating and cooling three or four times, to prevent pitting.

W. J. MERTEN: We have not obtained the results we reported in that manner. We heat the bath to temperature and endeavor to keep it there continuously.

MR. FORD: The quenching solution would naturally change from time to time, would it not, thus making it necessary to renew it?

W. J. MERTEN: The suspended ingredients are being continually carried away; it is, of course, necessary to supplement those as the action continues, in order to keep the mixture permanent.

H. C. KNERR: I would like to ask Mr. Merten to again state the composition of his quenching medium.

W. J. MERTEN: Three hundred gallons of water, containing 150 pounds sodium chloride, 100 pounds of lime and 75 pounds of sodium cyanide.

R. M. BIRD: I believe Mr. Merten stated that the trouble which he experienced was commonly known as fugitive soft spots, that is—if a piece of steel were quenched, certain soft spots would appear. If this was then heated up and quenched again, the soft spots would become hard, and the soft spots appear elsewhere. Therefore, it means that the steel is not decarburized.

W. J. MERTEN: I stated that decarburization and oxidation were superficial, which could be removed by ordinary polishing methods and no evidence of any deep oxidizing effect could be found. However, we did find sufficient evidence of diminished cooling effect, which reduced the amount of hard or martensitic constituent in the quenched steel. Particular care was taken that the salt bath was purified so as not to decarburize.

R. M. BIRD: The superficial decarburization would not be enough to affect the cutting edge of the tool, would it?

W. J. MERTEN: No, it would not.

R. M. BIRD: In other words, we would assume that your difficulty is not what is usually known as decarburization. Is that not right?

W. J. MERTEN: I believe it was stated in that manner.

R. M. BIRD: As I understand it, Mr. Merten's paper deals with an incomplete hardening of the steel and a way to correct it. The steels 0.90 to 1.00 per cent carbon were heated with a particular salt to a temperature, and did not develop decarburization. This has no bearing on the fact that one of the other speakers using another mixture, perhaps a higher temperature, finds decarburization. In other words, the two points are entirely dissociated.

W. J. MERTEN: Yes, I believe I stated when the subject was introduced that my paper did present an entirely different aspect of salt bath heating. I do not think I touched on the salt bath composition mentioned by one of the other speakers, because I do know that ordinarily the statement and facts are correct. My problem was an entirely different one, but an intensely interesting and valuable one to the heat treater. However, I would like to repeat that without remedial methods we would have had pitting and decarburization in the salt bath.

MR. BROWN: I would like to ask Mr. Merten if he has done anything with barium as an absorbent salt.

W. J. MERTEN: We do not use barium salt. We are not running any barium chloride baths at the present time on high speed work, although we

have tried the boric acid charcoal mixture on such salt baths with excellent results.

MR. BROWN: I would like to ask about the preventing of the localized decarburization.

W. J. MERTEN: To prevent decarburization, purifying of the salt bath is essential. This precaution must be observed with any salt bath, and a boric acid charcoal scavenger is the only positive means which will assure results.

J. S. VANICK: With respect to the decarburization feature which aroused considerable discussion in Mr. Merten's paper, it might be well to note that a "carburized" or aluminum-lined receptacle had been used as a container for the salt bath experiments described. Metallic aluminum is commonly used as a scavenger and a ferro-aluminum compound such as the container coating would be composed of, might act similarly. The probable deoxidation of the salt bath by reason of a preferential oxidation of the available aluminum might serve to retard or prevent the decarburization of the steel. An inquiring observation upon coated containers, as well as upon the work being treated, might yield some information upon this point.

DENSITY AND X-RAY SPECTRUM OF HARDENED BALL STEEL TEMPERED AT VARIOUS TEMPERATURES

By K. Heindlhofer and F. L. Wright

Abstract

The X-ray diffraction method was applied to reveal the nature of a transformation occurring when tempering quenched ball steel. This transformation is evidenced by density and hardness measurements and by the microstructure. The X-rays show that austenite is invariably present in the quenched specimens, and that this austenite transforms at temperatures between 200 and 260 degrees Cent., and that during this transformation the formation of an intermediate hard product is indicated. This intermediate product will simultaneously be subjected to tempering due to the prevailing temperature.

Object of Investigation

PREVIOUS investigations[1] have shown that the density of hardened carbon steel does not increase steadily over the whole tempering range, but that an irregularity occurs between 200 and 270 degrees Cent. (392 and 518 degrees Fahr.). It is generally believed that this irregularity is caused by the sudden disappearance of austenite. The object of the present investigation was to repeat these measurements of density, using steel balls for test specimens, and to correlate the changes in density which occur on tempering with the corresponding changes in hardness, microstructure and atomic lattice.

Preparation of the Specimens

Test specimens were made up in the form of ½ and $\frac{9}{16}$-inch

[1]Charpy and Grenet, Society d'Encouragement de Science, page 464, 1903. "Recherches sur la Trempe et le Revenue du Fer et de l'Acier," by Ed. Maurer, *Revue de Metallurgie*, page 711, 1914. Hanemann and Schultz, *Stahl und Eisen*, 1914.

A paper presented before the Boston Convention of the Society, September, 1924. Of the authors, K. Heindlhofer is research engineer with the SKF Industries, Inc., and F. L. Wright is metallurgist with the Atlas Ball Co., Philadelphia.

steel balls. Two coils of wire having the following chemical analysis were used for this purpose, so that balls of one size were made from a single coil of wire.

	½-inch Balls	$\frac{9}{16}$-inch Balls
Carbon	1.06 Per Cent	0.98 Per Cent
Chromium	0.71 Per Cent	0.55 Per Cent
Manganese	0.40 Per Cent	0.25 Per Cent
Silicon	0.32 Per Cent	0.27 Per Cent
Sulphur	0.015 Per Cent	0.018 Per Cent
Phosphorus	0.020 Per Cent	0.014 Per Cent

Both the ½-inch and the $\frac{9}{16}$-inch balls were separated into two lots before hardening, and each lot quenched from a different temperature, as follows:

The ½-inch balls were quenched in water from 800 and 915 degrees Cent. (1472 and 1679 degrees Fahr.)

The $\frac{9}{16}$-inch balls were quenched in oil from 865 and 950 degrees Cent. (1589 and 1742 degrees Fahr.)

Each lot, representing a different heat treatment, was then ground and polished to the final size, without tempering.

Density at Room Temperature After Tempering

The changes in density due to tempering were found by measuring the changes in diameter of twenty balls tempered for thirty minutes at each of the temperatures shown in Table I. Sets of twenty untempered balls were selected for each new tempering temperature. The average of the several diameters as measured at 20 degrees Cent. (68 degrees Fahr.), when calculated as volume and divided into the average weight of ten balls, gave the density. The diameters were measured within ± .000025-inch and the balls were round within these same limits. The error in weighing was about ± .0001 gram. The deviation from the average values for weight and diameter of any single ball was small among the balls quenched from the higher temperatures. Slightly greater variations from these averages were noted among the balls quenched from the lower temperatures.

The densities are as follows:

Table I

Density (grams per cubic centimeter)

Tempering Temperature Degrees Cent.	½-inch Balls Water Quenched		$\frac{5}{16}$-inch Balls Oil Quenched	
	800 Degrees Cent.	915 Degrees Cent.	865° Degrees Cent.	950 Degrees Cent.
Undrawn	7.757	7.745	7.788	7.767
80	7.757	7.746	7.788	7.768
100	7.758	7.750	7.788	7.769
120	7.763	7.759	7.788	7.771
150	7.765	7.763	7.788	7.773
177	7.766	7.764	7.789	7.775
205	7.767	7.765	7.7885	7.776
231	7.7657	7.760	7.781	7.765
260	7.768	7.751	7.783	7.762
288	7.774	7.755	....	....
316	....	....	7.795	7.780
370	7.793	7.784	....	....
730	7.812	7.809	....	....

The values contained in Table I are plotted in Figs. 1 and 2. All four density curves follow the same general form. The density of the balls as quenched is lowered by increasing the quenching temperature both for oil and water quenching. The density is also lowered by increasing the speed of cooling, as shown by the differences in density between the oil and water quenched balls.

The curves seem to be the resultants of two component curves. The fundamental curve covers a wide range and corresponds to a transformation from light to dense, while the superimposed short range transformation indicates a change from dense to light. The irregularity on the resultant curve will be more pronounced when more substance of the latter kind is transformed over this short range.

A comparison of the four tempering density curves does not permit a decision about the accurate location of the starting point for the short range transformation. As far as may be ascertained, this start occurs for the type of steel under investigation, at approximately the same tempering temperature, independent of the quenching temperature and the speed of quenching. The transformation is retarded, however, by the higher quenching temperature, independent of the rapidity of cooling.

The early period of the wide range transformation as covered by the range up to the tempering temperature of 200 degrees Cent. (392 degrees Fahr.) shows the density increasing

at different rates, depending on the heat treatment used before tempering. The greatest rate of change during this early tempering period is noted in the balls quenched at the fastest speed,

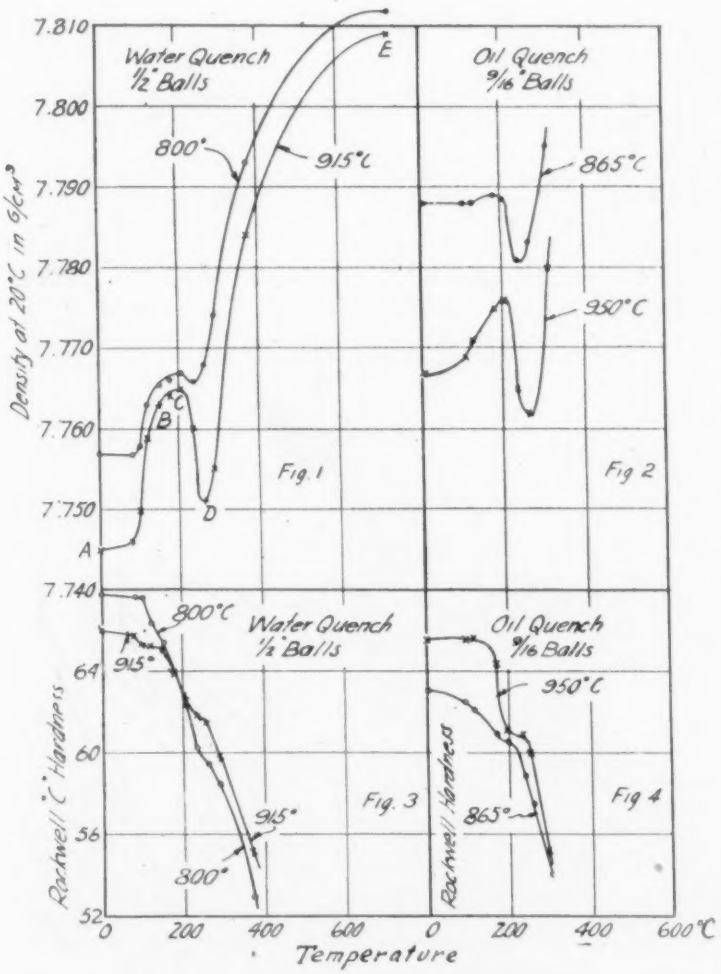


Fig. 1—Density in Grams Per Cubic Centimeter of ½-Inch Balls Quenched at 800 and 915 Degrees Cent. Into Water and Tempered at Various Temperatures.

Fig. 2—Density in Grams Per Cubic Centimeter of $\frac{9}{16}$-Inch Balls Quenched at 865 and 950 Degrees Cent. Into Oil and Tempered at Various Temperatures.

Fig. 3—Rockwell Diamond Cone Penetration Hardness of ½-Inch Balls Quenched at 800 and 915 Degrees Cent. Into Water and Tempered at Various Temperatures.

Fig. 4—Rockwell Diamond Cone Penetration Hardness of $\frac{9}{16}$-Inch Balls Quenched at 865 and 950 Degrees Cent. Into Oil and Tempered at Various Temperatures.

that is, from a high temperature into water. The slowest rate of change, where practically no change in density occurs on tempering up to 200 degrees Cent., is found in balls quenched in oil

from the low temperature of 865 degrees Cent. (1589 degrees Fahr.). It is evident from this that the transformation which takes place on tempering at low temperatures up to 200 degrees Cent. may also occur during quenching, and the amount of transformation occurring during quenching is dependent on the quenching speed.

Changes in Hardness Due to Tempering

Four balls were selected for Rockwell diamond cone penetration test from each lot representing one combination of quenching and tempering temperatures. The individual readings were found to be consistent. The results shown in Figs. 3 and 4 are given in Table II.

Table II

Rockwell Diamond Cone Penetration Hardness

	½-inch Balls Water Quenched		$\frac{9}{16}$-inch Balls Oil Quenched	
Tempering	800	915	865	950
Degrees Cent.	Degrees Cent.	Degrees Cent.	Degrees Cent.	Degrees Cent.
Untempered	67.9	66.0	63.1	65.6
80	67.7	65.8	...	...
100	67.5	65.3	62.6	65.6
120	66.4	65.3	62.2	66.0
150	65.4	65.2	...	...
177	63.9	64.0	61.0	64.4
205	62.3	62.7	60.7	61.2
231	61.2	61.8	58.9	61.2
260	59.5	61.5	57.5	60.0
288	58.5	59.8	...	...
316	...	...	54.0	55.3
370	53	55.2	...	...

An examination of the hardness curves shows several interesting details. The untempered water quenched balls are harder than the balls quenched in oil. In the case of the water quench, the hardness in the untempered condition is lowered by increasing the quenching temperature. The opposite is true for oil quenching, however, where the hardness in the untempered state is increased by raising the quenching temperature.

The hardness remains unchanged up to 100 degrees Cent., with the exception of the balls quenched in oil from 865 degrees Cent. (1589 degrees Fahr.), where a gradual reduction of hardness with tempering is immediately noticed. Beyond about 150 degrees Cent., hardness drops rapidly and proportion-

ally with the temperature, with the exception of an irregularity at about 200-260 degrees Cent., which suggests the formation of a harder substance from a softer one. This irregularity corresponds with the irregularities in density. This phenomenon is analogous to the secondary hardness noticed at higher tempering temperatures in high speed steel[2] and high carbon, high chromium steels[3] following suitable heat treatments.

Microstructures

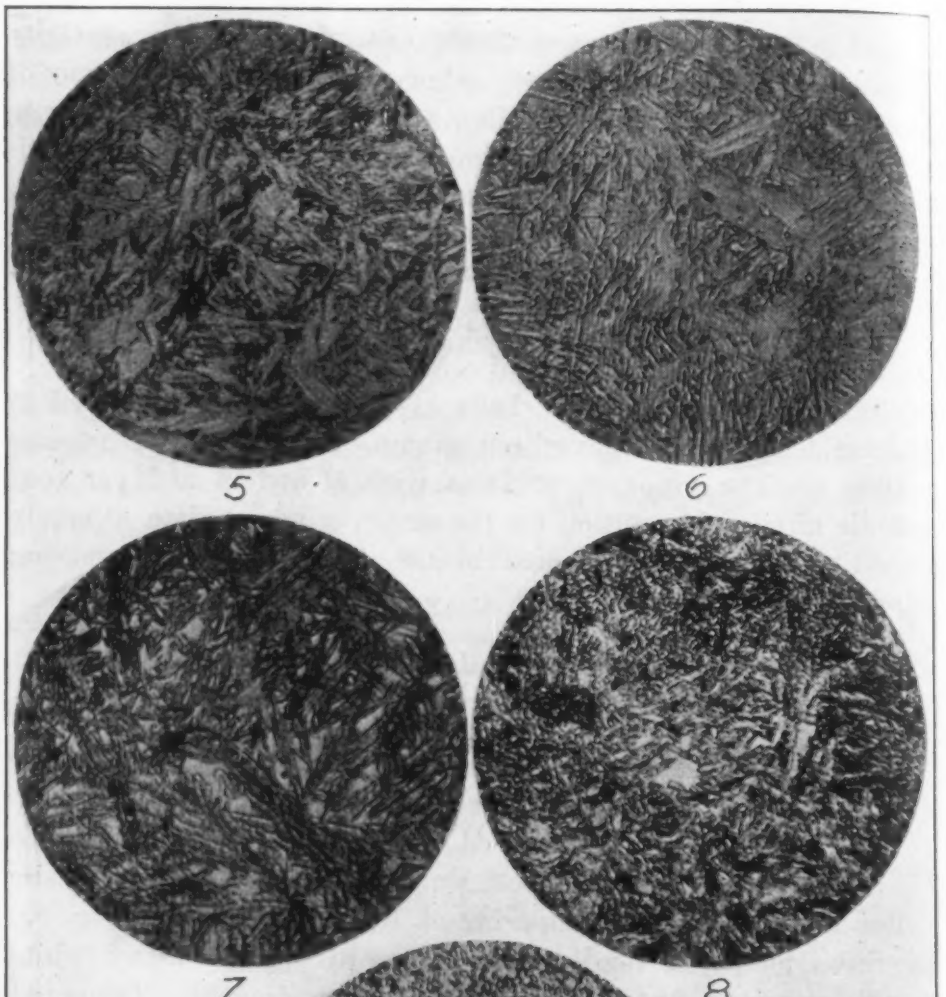
The structures of a few balls as quenched and tempered at different temperatures have been examined under the microscope at 1000 x. The prepared surfaces were etched in a 1 per cent alcoholic nitric acid solution for the same periods of time. Certain interesting changes were noted in the structure with increasing tempering temperatures.

½-Inch Balls Quenched in Water at 915 Degrees Cent. and Tempered to Different Temperatures

As quenched, the surface was only slightly attacked by the etching reagent. The martensite needles were large, as shown in Fig. 5. A few undissolved cementite grains, negligible in quantity, were scattered through the structure. The martensite needles are darkened by tempering at 150 degrees Cent. (Fig. 6), and these tempered needles are contrastd against many white interfilling grains, unattacked by the etching reagent. Tempered still higher to 205 degrees Cent. (401 degrees Fahr.), the structure is sharply defined by the almost black martensitic needles contrasted against the interfilling white (austenite) grains, as shown in Fig. 7. At 260 degrees Cent. (500 degrees Fahr.) the martensitic needle structure has almost disappeared, and only faint outlines are distinguishable. The structure of broken down martensite is uniform throughout, except for a few white unattacked grains (Fig. 8). Tempered at 370 degrees Cent. (698 degrees Fahr.) the freshly formed cementite grains are visible in the tempered martensite, and at 730 degrees Cent. (1346 degrees Fahr.) the structure is granular pearlite (Fig. 9).

[2] "Relation of High Temperature Treatment of High Speed Steel to Secondary Hardness and Red Hardness," by Howard Scott, Scientific Paper, No. 395, Bureau of Standards.

[3] "Secondary Hardness of Austenitized High Chromium Steels," by E. C. Bain, TRANSACTIONS of the American Society for Steel Treating, Vol. 5, No. 1, January, 1924.



Photomicrographs of ½-Inch Balls Quenched at 915 Degrees Cent. Into Water. 1000 x. Fig. 5—As Quenched. Fig. 6—Tempered 30 Minutes in Oil at 150 Degrees Cent. Fig. 7—Tempered in Oil 30 Minutes at 205 Degrees Cent. Fig. 8—Tempered in Oil 30 Minutes at 260 Degrees Cent. Fig. 9—Held One Hour at 730 Degrees Cent. in Electric Furnace. Balls Were Packed in Cast Iron Chips.

½-Inch Balls Quenched in Water at 800 Degrees Cent. and Tempered at Different Temperatures

As quenched, the structure shows fine martensitic needles hardly visible under the microscope, and many undissolved cementite grains of medium size scattered uniformly through the structure. On tempering, the only change noted was the darkening of the martensitic needles until at 370 degrees Cent. (698 degrees Fahr.) it had entirely broken down and lost its identity.

Microstructure of 9/16-Inch Balls Quenched at 950 Degrees Cent. in Oil and Tempered at Different Temperatures

The structures of the balls quenched in oil at 950 degrees Cent. (1742 degrees Fahr.) and tempered to different temperatures, are similar to the structures found in the balls quenched at 915 degrees Cent. (1679 degrees Fahr.) into water and tempered at similar temperatures. The martensitic structure is made pronounced with increasing tempering temperatures by the darkening of the needles as contrasted against a considerable number of white unattacked (austenite) grains. These white grains, present in large quantities in balls tempered at 205 degrees Cent., have almost disappeared in the balls tempered to 260 degrees Cent

Microstructure of 9/16-Inch Balls Quenched at 865 Degrees Cent. in Oil and Tempered at Different Temperatures

The structure as quenched etches rapidly, similar to the tempered structure of the water-quenched balls. The martensite is very fine and contains a number of small undissolved cementite grains. Troostite grains in the form of irregular needles are scattered through the structure. With increasing tempering temperatures the martensitic needles are darkened. At the same time the troostitic needles lose their contrast against the tempered martensitic background until after tempering to 316 degrees Cent. they are almost completely merged into the tempered martensite structure.

Crystal Lattice

Apparatus

The apparatus used for X-ray crystal analysis was a modification of the well-known photographic method, in which the camera was replaced by a spectrometer and ionization chamber. The X-rays are diffracted from a thin layer beneath the surface

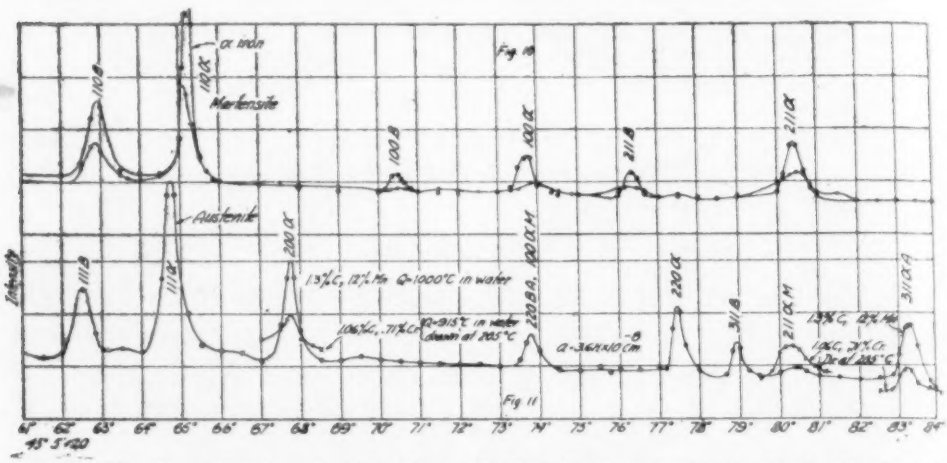


Fig. 10—X-ray Spectra of Alpha Iron (Melting Bar) and of Fine Martensite in 1.31 Per Cent Carbon Steel. Almost All Cementite is Dissolved. Fig. 11—X-ray Spectra of Austenite in 1.3 Per Cent Carbon 12 Per Cent Manganese Steel Quenched from 1000 Degrees Cent. in Water, and of Ball Steel Quenched from 915 Degrees Cent. in Water, Tempered at 205 Degrees Cent.

of a block-shaped specimen, placed at the center of the spectrometer table. The diffracted rays pass through a slit so mounted on the table that its angular position may be accurately determined. The rays enter an ionization chamber containing methyl bromide. The ions so produced are caught by an insulated electrode connected to a quadrant electrometer. The charge of the ions produced per second is a measure of the intensity of the reflected X-rays.

The angles at which the peak intensities occur are best determined by moving the slit in small increments and measuring the intensity of ionization at each position. If these intensities are plotted at different angles, curves are obtained similar to those shown in Figs. 10, 11, 12 and 13. The peaks correspond to the lines seen on the photographic film. An obvious advantage of this method is that it shows the intensity of lines in a quantitative manner, hence the ionization method may be used with advantage

quantitatively to estimate the amount of a given ingredient present.

Discussion of Spectra

The spectra of the different metallographic constituents whose transformations are suspected, must be determined, in order that the changes which take place on tempering may be identified by

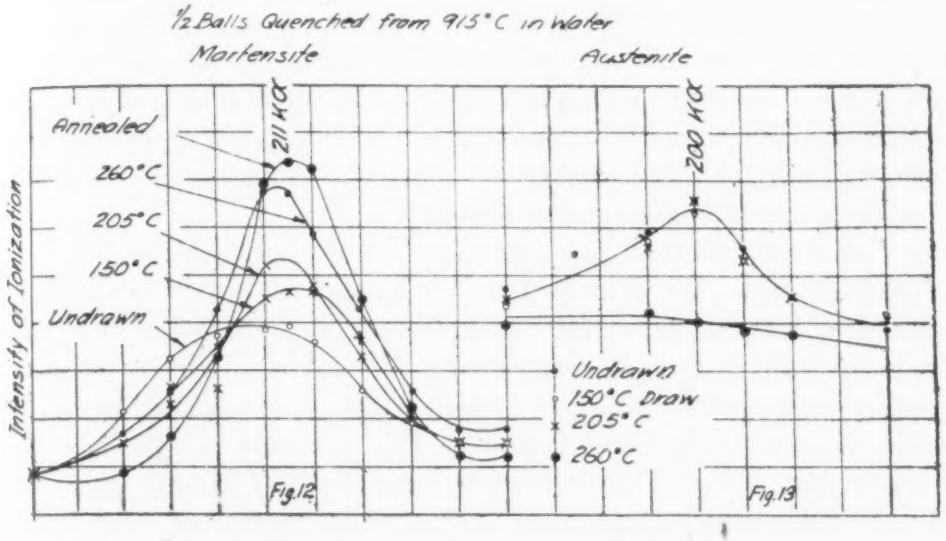


Fig. 12—Changes of the 211 KX-Line in the X-ray Spectrum of Martensite in Ball Steel Quenched in Water from 915 Degrees Cent. Fig. 13—Changes of the 200 KX-Line of Austenite in Ball Steel Quenched in Water from 915 Degrees Cent. with Drawing, Show That Austenite Disappears in Bulk Between 200 and 260 Degrees Cent.

the X-ray method. Fig. 10 shows part of the spectrum of a sample of martensite compared with a part of the ferrite spectrum.* The most important difference between the two is the decreased intensity of the lines for martensite as compared with the lines for ferrite. On close examination it will be found also that certain of the lines for martensite are shifted slightly with respect to the ferrite lines, some to the right and some to the left. Fig. 11 gives the spectrum for austenite in a 1.30 per cent carbon, 12.00 per cent manganese steel quenched from 1000 degrees Cent. (1832 degrees Fahr.) into water. The peak at 80 degrees-30 minutes indicates the presence of a small amount of martensite not visible under the microscope.

X-ray crystal analyses have been used in the present investigation to definitely prove whether or not austenite is present in

*See foot note 6.

hardened ball steel as quenched, and to identify the critical range on the density curves between 200 and 260 degrees Cent. as a transformation of this retained austenite, so denoted by other investigators using microscopic,† thermal[1] and electric resistance[2] methods.

The next step was to select the specimen, preferably one which showed the greatest sign of transformation evidenced by the hump on the density curve, and determine its spectrum. The ½-inch ball quenched in water from 915 degrees Cent. (1679 degrees Fahr.) (see Fig. 1) was selected for this purpose. Instead of going over the complete spectrum, it was considered sufficient to determine the location of two austenite lines only. The results are indicated by the crosses in Fig. 11. The match with the austenite spectrum (Fig. 11) is perfect.

To show whether the austenite present in the ½-inch ball quenched from 915 degrees Cent. is broken down on tempering, the austenite peak occurring at 67 degrees 40 minutes, is replotted in large scale in Fig. 13 and here it is compared with three other ones corresponding with the most important tempering temperatures, *i. e.*, with the point B and C, Fig. 1, where the transformation begins, and at D, where it is completed as judged from the density-tempering-temperature curve. All tempered specimens were X-rayed at room temperature.

From these curves, Fig. 13, it appears that there is little or no breakdown of austenite until a tempering temperature of 200 degrees Cent. is exceeded. Almost all of the austenite has disappeared, however, in the sample drawn at 260 degrees Cent.

In order to reveal the nature of the product of this transformation, one would be tempted to again consult the X-rays. Since it is likely that austenite on tempering changes either to martensite or ferrite plus cementite, the changes of the prominent line (211) shown in Fig. 10, were observed at the different degrees of tempering. These changes observed at room temperature are plotted in Fig. 12. The intensity increases gradually with progressive tempering, and it is due to two factors. First, the bulk of the specimen consists of martensite, which gradually approaches

†See foot note 1.

[1] "Thermal and Physical Changes Accompanying the Heating of Hardened Carbon Steel," by Scott and Movius, Scientific Paper, No. 396, Bureau of Standards.

[2] "Studies of Hardened and Drawn Structure of Carbon Steel," by B. D. Enlund, *Jernkontorets Annaler*, September, 1922, pages 389-423.

the ferritic state, characterized by tall peaks. Second, the freshly formed ferrite or martensite produced by the decomposition of the austenite on tempering adds to the scattering. Since both of

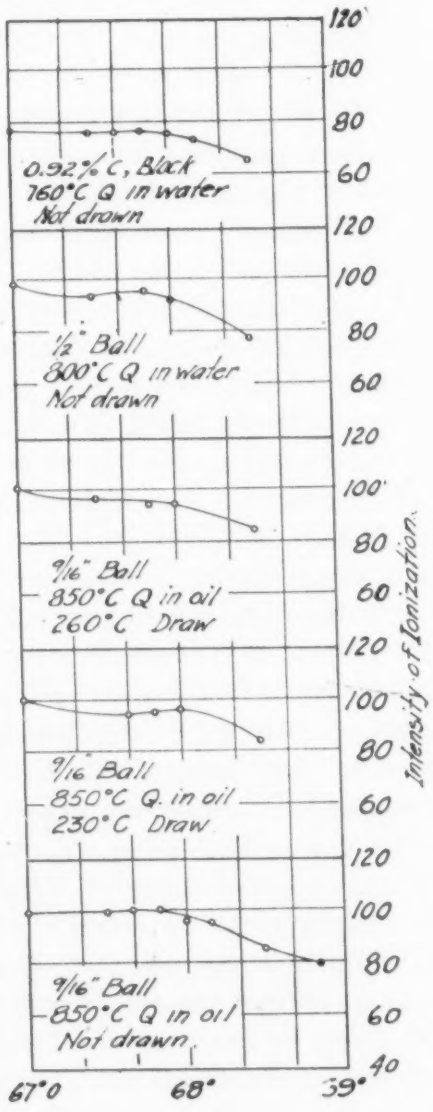


Fig. 14—The Existence of the 200 KX-Line Shows About 3 Per Cent Austenite Under Conditions Where It Would be Difficult to See by the Microscope at the Uusual Magnifications.

these substances scatter in a similar way, it is difficult to decide whether the growth between 205 and 260 degrees Cent. is due to added martensite or added ferrite.

A careful observation of the peaks shows a slight shift

between the maximi of the 205 and 260 degrees Cent. curves, indicating some added martensite. This result is corroborated both by the changes in density and hardness. The density of pure austenite may be evaluated from plot Fig. 11, which gives 7.83 grams per cubic centimeter, in good agreement with the value given by Westgren.[7] This value is nearly the same as that of annealed ball steel. The density of martensite of a small specimen 0.8 per cent carbon steel, quenched from the lowest possible temperature where troostite is just avoided, is 7.75 grams per cubic centimeter.[6] Hence, a change from austenite to ferrite plus cementite in the 915 degrees Cent. water quench ½-inch ball specimen will not cause an appreciable change in density, while a change to the light martensite will decrease the density the same as observed between the points C and D, Fig. 1, where the transformation occurs. The superimposed hardness effect, seen as a local change in the slope of the hardness-tempering curves at the austenite transformation range, also indicates the formation of a hard substance from a soft one.

Austenite, while disappearing in bulk within a short range of tempering temperature, has not completely transformed over the range investigated, *i. e.*, 260 degrees Cent. The X-ray peak in Fig. 13 indicates an amount of the order of 3 per cent, which remains in the specimen after 30 minutes tempering at 260 degrees Cent. Fig. 14 shows that about the same amount was found in the oil quenched ball specimens, and even a 0.92 per cent carbon steel with no chromium, quenched in water from 760 degrees Cent., shows a small percentage of austenite.

There are a few remarks to be made on the breakdown of martensite. It is generally supposed that in carbon and alloy steels of the type used in the present investigation, martensite is completely broken down to form troostite when hardened samples are tempered above 300 degrees Cent. The change in microstructure indicated in Figs. 6, 7 and 8, and the increase in intensity of the "martensite" peaks shown in Fig. 12, both appear to bear this out. The fact must not be overlooked, however, that the density and hardness change only slightly at low tempering

[6] "Crystal Structure of Hard Steel," by K. Heindlhofer, *Physical Review*, 1924, page 427. (The curves showing the spectrum of martensite and ferrite were borrowed from this paper.)

[7] "Roentgen Spectrographic Investigations of Iron and Steel," by A. Westgren, British Iron and Steel Institute, 1921, page 315.

temperatures as compared with the change in density and hardness which take place on tempering at the higher temperatures. There is not sufficient experimental evidence available at present to discuss this point.

Conclusions

1. Chromium ball steel is shown by X-ray methods to contain both martensite and austenite under all conditions of quenching which were used in these experiments.

2. Two transformations occur when hardened balls are tempered, as indicated by the changes in density.

3. One is a transformation from light to dense, and is shown by the microscope and X-rays to be a breakdown of martensite. This transformation proceeds over a wide range.

4. The second transformation is confined to the short tempering range between 200 and 260 degrees Cent. It is a change from dense to light and is shown by X-rays to be the transformation of the bulk of the retained austenite to martensite.

5. Although the characteristic martensitic needle structure has disappeared at a tempering temperature of 300 degrees Cent., there is shown to be a constant increase in density with increasing tempering temperatures beyond 300 degrees Cent., corresponding with a gradual drop in hardness.

In conclusion the authors wish to express their appreciation to the SKF Industries for the laboratory facilities used in carrying out this investigation, and to the Research Section of the Randal Morgan Laboratory of Physics, University of Pennsylvania, for the use of their X-ray equipment. The authors wish to especially thank Dr. Styri, of the SKF Research laboratory, for his helpful suggestions and criticisms during the preparation of this paper. Acknowledgment is made to H. O. Walp, SKF Research laboratory, for the microphotographs used in Figs. 5, 6, 7, 8 and 9.

Discussion of Paper

Dr. Haakon Styri: It may be of interest, in connection with Heindlhofer's and Wright's paper, to describe some measurements of the expansion during heating of similar material. In a simple home-made dilatometer of great sensitivity, a number of heat treated balls were subjected to rapid or slow heating, and the expansion against temperature and time recorded as

shown in Figs. 1, 2 and 3. A hole for a fine base metal thermocouple was drilled in the ball before heat treatment, so that the temperature of the specimen could be taken directly.

All the curves show two definite periods of contraction superposed on the regular expansion due to increase in temperature. Slow heating will cause the contraction to start at a somewhat lower temperature. If a specimen is cooled to room temperature after the low temperature contraction, there is usually no indication of a repetition of this change unless the first heating has been rapid or has ended at a too low temperature (Fig. 1). If the second transformation has started before the cooling took place, this may cause re occurrence of low temperature transformation.

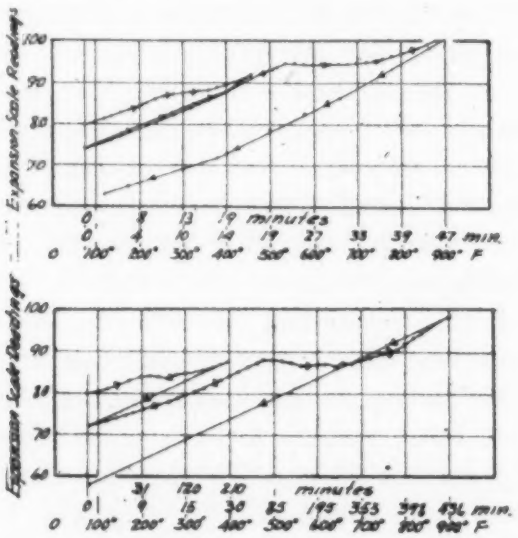


Fig. 1—Showing Tempering Curves on Water Hardened Chromium 10 Millimeter Steel Balls. The Samples have been Cooled to Room Temperafure After Passing the First Transformation. Note Slight Reoccurrence of Low Transformation in the Second Curves for Slow Heating. The First Slow Heating Stopped at 400 Degrees Fahr. The Upper Curves Represent Heating and the Lower Curves Represent Slow Heating Conditions.

Comparing these curves with the data given in the paper, it is evident that the low temperature contraction corresponds with a more regular orderly building up of the alpha iron lattice from a more or less distorted condition.

Etching and microstructure also indicates a corresponding change and, possibly, that there is a slight formation of cementite. By means of his sensitive magnetic measurements, Honda[1] found no indication of cementite after quenching and only a very slight formation after tempering at 150 degrees Cent. (302 degrees Fahr.) The curves representing the electric measurements of Enlund are very similar to Figs. 1, 2 and 3, and the change shown at the low temperature was judged as separation of cementite from martensitic needles.

The second contraction period corresponds with the disappearance of the

[1]Journal of the Iron and Steel Institute, 1918, II, page 375.

austenite, and it is interesting to note that it is preceded in several instances by an expansion which must be due to a transformation of gamma to alpha iron. That this expansion is not always seen when gamma iron is present, is explained by the superposition of a contraction due to building up of the alpha lattice from the distorted structure caused by the transformation.

Grain growth and closing up of voids from slips originally caused by the internal mechanical work during hardening, will increase this contraction. A

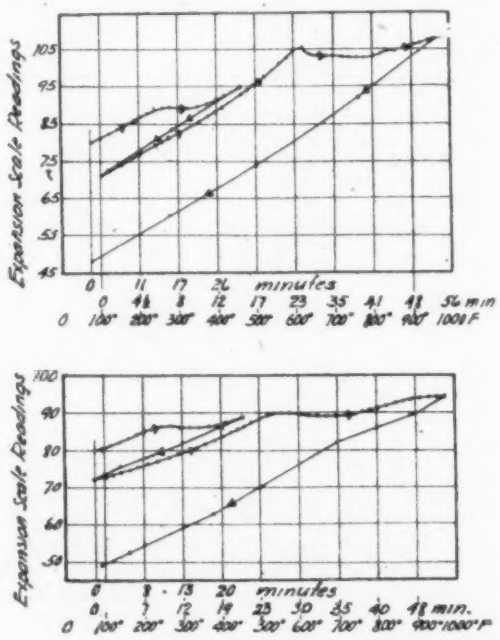


Fig. 2 — Upper, Tempering Curves of Chromium Steel Ball ½-Inch Hardened in Water from 1680 Degrees Fahr. (916 Degrees Cent.) Showing Slight Expansion from 500 to 600 Degrees Fahr. Lower, Tempering Curve of 0.90 Per Cent Carbon Steel Hardened from 1400 Degrees Fahr. in Water.

reference to the curves 1, 2 in the author's paper is enough to indicate this result of the internal mechanical work. The high temperature quench gives the larger volume, although the specimen has a higher content of the relatively denser austenite.

Explained in a little more detail, it means that when a specimen is quenched from a higher temperature, the sample has frozen stiff on the outside while the interior still has a larger volume because of its higher temperature. When the interior contracts due to further cooling the exterior cannot follow completely. In less rapid cooling the difference between outside and inside is less pronounced.

It may be assumed that some atoms during the transformation in hardening or tempering do not belong to either the alpha or the gamma lattice, and therefore form an armorphous structure.

The gamma to alpha change is practically completed early in the second

contraction period, but the contraction goes on to higher temperatures approaching full annealing. The etching and magnetic measurements referred to, show the formation of cementite principally in this second period.

Enlund gave practically a positive identification of austenite (or solid solution) after hardening, by means of resistance measurement, and showed that it would transform to alpha iron when tempered above 260 degrees Cent. This is now substantiated by the identification of gamma iron in the hardened steel by X-rays. The conclusion of many investigators that more or less

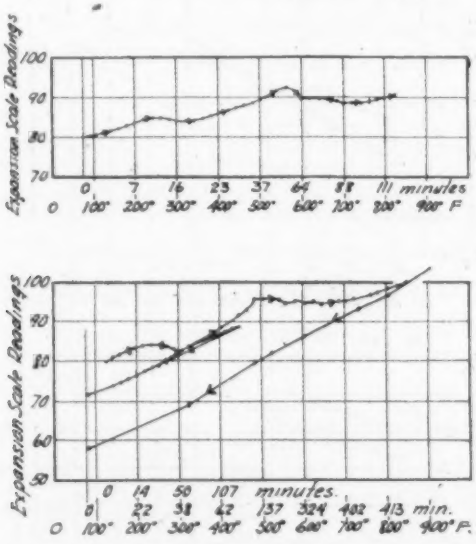


Fig. 3 — Tempering Curve of Chromium Steel Ball Quenched in Water from High Temperature, 1850 Degrees Fahr. (1010 Degrees Cent.). Note Expansion Before Second Contraction Period. The Upper Curves Represent Rapid Heating and the Lower Curves Represent Slow Heating Conditions.

gamma iron probably is present in all hardened untempered steel, seems therefore justified. I am inclined to believe that the second contraction period described here is in itself a positive proof of the presence of gamma iron. The first contraction period corresponds to a more orderly building up of the alpha lattice, but it should be noted that this first period is not very distinct in oil-hardened steel, or in water-hardened steel tempered at 150 to 175 degrees Cent. Both has a distinct martensitic structure. It is my opinion, therefore, that the second contraction period is the most characteristic of the presence of martensitic structures, as generally understood.

We can now draw a new picture, or rather brush up an old one,[2] of the changes taking place during rapid cooling (hardening). In the grains of austenite (solid solution) alpha iron will first form on cleavage planes and grain boundaries, and will, during the change, try to repulse the dissolved carbide to the adjacent gamma iron. This will be enriched in carbide on the boundary and will try in turn to repulse the carbide. I say carbide deliberately and not cementite, which is the crystallized form we observe in the

[2] *Journal* of American Steel Treaters Society, Vol. I, page 294.

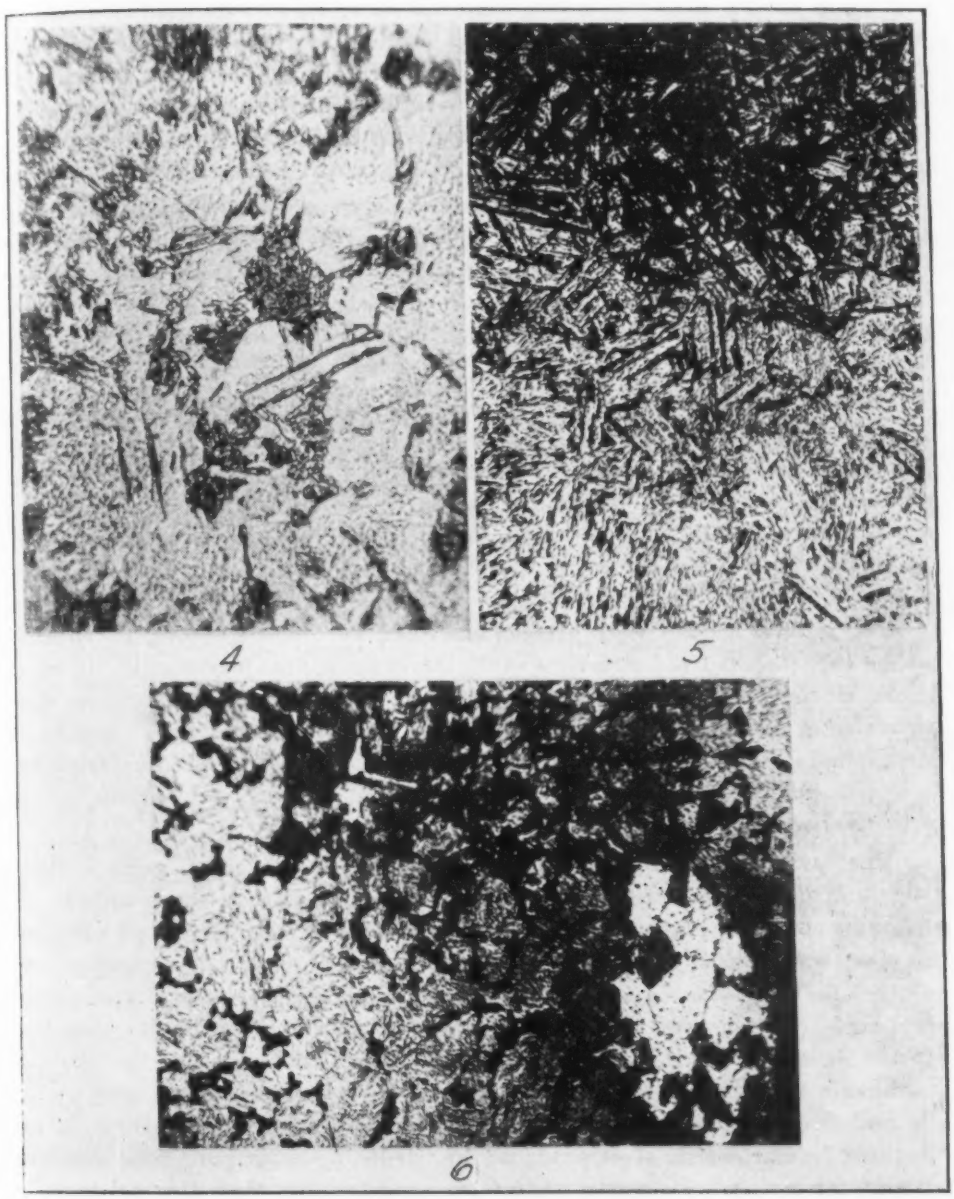


Fig. 4—Chromium Steel Quenched in Oil from 1510 Degrees Fahr. 1000 x. Secondary Ferrite Needles. Fig. 5—Carbon Steel (0.30 Per Cent) Quenched in Water from 900 Degrees Cent. 5 Minutes Heating. 250 x. Fig. 6—Carbon Steel (0.30 Per Cent) Quenched in Water from 800 Degrees Cent. 5 Minutes Heating. 250 x. In Figs. 5 and 6, the Variation in Martensite is Due to Uneven Carbon Content Caused by Insufficient Soaking.

microscope. The carbide will tend to get rid of excess iron atoms to form cementite, but evidence is that it does not succeed in doing this until tempering. Some gamma iron with its dissolved carbide remains untransformed, possibly even enriched in carbide. Because it is undercooled it is in a strained condition.

According to the speed of cooling and the initial temperature of harden-

ing, more or less distorted alpha iron and more or less gamma iron will be present in the hardened steel. Rapid cooling (waterquench) favors much distorted alpha iron, while high initial temperature favors retention of much gamma iron. It may be possible, by certain rate of cooling, to prevent retention of any gamma iron, but probably with the formation of troostite and not martensite. At any rate, the change is gradual and progressive.

We can in this find an explanation of previously described formation of so-called secondary ferrite,[3] as it was first named by Hultgren, which is found in comparatively slowly cooled parts of alloy steel during quenching. Needles of ferrite are actually found adjacent to martensite. Fig. 4 shows a sample which is not a freak. We find it often, more or less developed, and can reproduce it.

When a large amount of austenite is present in the quenched sample, it is usually easily distinguished in the microscope, but when present in small quantities, austenite has not yet been identified that way. We know that martensite produced by quenching steels of different carbon content will look different, and difference can be shown in one and the same sample when the time at quenching temperature has been too short for equalizing, as shown in Figs. 5 and 6. This variation may even be apparent in individual needles. In fact, if only needles were present and they were homogeneous, no contrast can be expected and the structure could therefore not be martensitic. In other words, martensite must contain gamma iron, and martensitic structures must be due to a mixture of austenite and partly transformed material (needles on background) or to transformed material in various degrees of transformation. It is not justifiable to say that sharply outlined needles are martensite. In correctly quenched steel they are hardly distinguishable.

The low temperature change was found to be associated with a darkening and a sharper outline of the martensite and with a more orderly arrangement of the alpha iron and some formation of cementite, and affecting the most transformed part of the martensitic structure, but it corresponds to only a small decrease in hardness. The hardness in martensitic steel drops very rapidly when the remaining network of austenite with its dissolved carbide transforms at the second period and simultaneously the distinct martensitic structure observed in the microscope becomes blurred and gradually goes over into troostite, sorbite and granular cementite. Cementite is not identified in martensitic steel produced by hardening from pure solid solution, without tempering. It seems, therefore, unreasonable that the hardness is due to cementite interfering with slip. But we have in the hardened steel a distorted lattice of alpha iron and a distorted lattice of unprecipitated carbide, as well as an undercooled solid solution (gamma iron) with lattice under severe strain, probably some amorphous material, and we have further small grain size, and mechanically deformed structure, all of which form obstruction to slip and therefore cause hardness. Cementite will undoubtedly increase hardness of pure iron in a degree depending on size and shape, but it is not therefore a necessary consequence that the hardness of martensite should be ascribed prin-

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[3]Chemical and Metallurgical Engineering, 1921, page 313.

cipally to the presence of submicroscopic cementite or to carbon atomically dispersed in alpha iron.

The name "slip interference" is, of course, still valid as it would be for most theories of hardening, and is much easier on the tongue than for instance, obstruction. If I may so express it, it is the disorderly conduct of the atoms of iron and carbon which causes the greatest hardness of hardened steel.

I am indebted to Mr. Walp, S. K. F. Research Laboratory, for his careful work in preparing these curves.

DR. ANCEL ST. JOHN: I think it might be worth while to get a picture of the way the atoms may be looked upon as being arranged in the various groupings. Westgren and Phragmen have shown, I think quite conclusively, that the only explanation of austenite is that the carbon atoms have gone into the open spaces between the iron atoms in the gamma iron structure, whereas in cementite the carbon atoms have actually replaced iron atoms in certain positions that would otherwise have been occupied by iron atoms, giving a special structure.

Now, we knew that when carbon atoms associate themselves with atoms of other substances in actual compounds, that is, the various carbides, that the carbon atoms have a distinct tendency to draw the other atoms closer to the carbon atoms, and even closer to each other than they would otherwise have been. In other words, they counteract by this drawing-in the change in density that would otherwise be introduced by replacing a heavy atom by a light atom. On the other hand, when the carbon atoms are introduced into spaces among the iron atoms, they spread out somewhat, so that the total volume is increased instead of being decreased. The consequence is that when a certain number of carbon atoms and a certain number of iron atoms are distributed as in austenite, the total volume that is occupied is greater than that occupied by the same carbon atoms and the same iron atoms if they are distributed in cementite.

Moreover, if some of the iron atoms are distributed in cementite and the balance in ferrite, again there is a total diminution of volume. That perhaps visualizes in a small degree the transformations that have here been discussed.

ENDURANCE PROPERTIES OF ALLOYS OF NICKEL AND OF COPPER – PART I*

By D. J. McAdam, Jr.

Abstract

This paper presents results of an investigation at the U. S. Naval Engineering Experiment Station. The investigation includes nickel, monel metal, constantan, cupro-nickel, several ternary alloys of nickel, copper, alpha bronze, alpha brass, aluminum bronze, Muntz metal, Naval brass and manganese bronze.

Endurance tests were made by the rotating-cantilever method and by the alternating-torsion accelerated-fatigue method. The results, presented in stress-cycle graphs, show that there is a definite endurance limit for each of these alloys. The abscissa at which the graph becomes nearly horizontal varies with the kind of material from about 20,000,000 *to* 200,000,000.

Ratios of the "endurance limits" to tensile, torsional and shearing strength are presented in tabular form. The "endurance ratios" of the various alloys differ greatly.

A tentative discussion is given of the effect of chemical composition on the endurance properties.

Introduction

WITHIN the past few years the endurance properties of steel have been thoroughly investigated (1 to 10).[1] "Endurance limits" of practically all kinds of carbon and alloy steels have been determined and have been correlated with other physical properties especially with tensile strength.

The ratios of endurance limits to tensile and torsional strength have been called "endurance ratios" (4). The ratio of the rotating-bend endurance limit to tensile strength has been called the "bend-tension static endurance ratio" (7). Investigations

*This paper is published by permission of the Secretary of the Navy.

[1]The figures appearing in parentheses pertain to the references appended to this paper.

A paper presented before the Boston Convention of the Society, September, 1924. The author, D. J. McAdam, Jr., is metallurgist with the U. S. Naval Engineering Experiment Station, Annapolis, Maryland.

of many kinds of steel have shown that this ratio varies from about 0.33 to 0.55 (4, 7). For the majority of carbon and alloy steels the ratio may be assumed to be about 0.50.

When it had been found that the "endurance limit" of steel is approximately proportional to the ultimate tensile or torsional strength and is practically independent of the ductility, it seemed reasonable to expect that the endurance limit of a non-ferrous metal would be found to depend only on the strength of the metal and that the static endurance-ratio for non-ferrous metals would be found approximately equal to the static endurance ratio for steel. Investigation of the endurance properties of non-ferrous metals had not progressed far, however, before it became evident that, if non-ferrous metals have an endurance limit, the ratio of the endurance limit to the tensile strength is usually lower than the ratio for steel.

Only within the past year, however, has there been available definite information about the endurance properties of a variety of non-ferrous metals and alloys. Even six months ago there was some doubt whether non-ferrous metals have an endurance limit (6) as definite as the endurance limit of steel. Within the past six months the endurance properties of many non-ferrous metals have been investigated (11). With the information now available it is possible to make an attempt to correlate the endurance properties of non-ferrous metals with their tensile and torsional properties, and to correlate the endurance properties of the various kinds of metal.

Before discussing the correlation of the endurance properties of metals, it is necessary to present data regarding the endurance properties of wrought non-ferrous metals. The data to be presented will be assembled in the form of stress-cycle graphs representing the results of investigation at the Naval Engineering Experiment Station. A few of these graphs, as indicated, have been presented in another recent publication (11). They are shown here so that a comparison may be made of these graphs with those of other metals. The great majority of the graphs here shown represent results of experiments not previously described. Following the presentation of data regarding the endurance properties of some non-ferrous metals, correlation of the endurance properties of these metals will be discussed.

TIGH
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Materials

The non-ferrous metals investigated were received in the form of round bars about an inch in diameter. The American Brass Company, the International Nickel Company, the Scovill Manufacturing Company, the Curtiss Bay Copper and Iron Works, and the Allis Chalmers Manufacturing Company generously cooperated in this investigation by furnishing material for this purpose.

Table I gives the chemical composition and method by which each material was wrought. Instead of trade names each material has been designated by a combination of letters.

Results of Tension Tests

Results of tension tests on the wrought non-ferrous alloys are given in Table II. The material designations are the same as in Table I. Instead of a yield point, Johnson's limit was determined whenever possible. Johnson's limit is the point at which the tangent of the angle between the stress-strain graph and the vertical has become 50 per cent greater than it was at the origin of the graph.

By elastic limit is meant the maximum stress that produces no permanent deformation. The proof stress is the stress that produces a permanent deformation of 0.0002 inches on a two inch gage length (0.01 per cent). The speed control of the machine below the proof stress was set to a point that would give a speed of 0.0367 inches per minute with no load on the machine. Above the proof stress the corresponding position of the speed control indicated 0.391 inches per minute.

Results of Static Torsion Tests

Results of static torsion tests are given in Table III. The specimens for these tests had a test diameter of ¾ inches. For calculating the nominal torsional strength the formula used for calculating stresses below the elastic limit was multiplied by three-fourths.

Rotating-Cantilever Tests

The specimen used in rotating-cantilever tests is essentially as previously described (1, 4). It has been modified somewhat, however, to eliminate unnecessary machining. The upper sketch of

Chemical Composition
All Values in Per Cent

Material	Material Designation	C	Ni	Cu	Sn	Al	Zn	Fe	Mn	Cr	Pb	Si	P	S
Nickel, Hot-Rolled	AW	.044	99.07	.159	....	....	....	0.59	.184	...	.....	.008	...	.025
Monel Metal, Cold-Rolled	BK	0.26	76.66	21.28	....	....	....	1.40	.258	...	None detected	.065	.023	.0063
Monel Metal, Cold-Rolled	BH	0.216	72.91	23.56	....	....	....	1.73	1.94	...	.....	.075	...	.007
Monel Metal, Hot-Rolled	AA	0.16	66.78	29.54	....	....	....	2.10	1.44	...	.....	.02	.019	.039
Constantan, Hot-Rolled	CE	....	44.68	53.77	None	....	....	0.52	1.14	...	None detected	...	...	...
Copper-Nickel-Chromium Alloy, Forged	D	....	34.15	58.93	None	....	....	1.04	1.61	4.14	None detected	.13	...	...
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	....	29.08	69.82	0.95	....	....	0.27	None	...	None detected	None	...	...
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD	....	19.75	74.01	None	....	5.17	0.34	0.75	...	None detected	...	...	...
Copper-Nickel Alloy, Cold-Rolled	B	....	19.23	80.34	....	....	None	0.27	0.12	...	None detected	...	...	...
Copper, Electrolytic, Cold-Rolled	BO	....	....	....	....	....	....	.0052	...	...	Less than .002	...	...	...
Copper, Electrolytic, Hot-Rolled	BU	....	....	....	....	....	....	.0058	...	...	Less than .002	...	...	...
Copper, Electrolytic, Cold-Drawn	CL	....	....	....	None	....	....	.02	...	...	None detected	...	...	...
Alpha Copper-Tin Alloy, Cold-Rolled	BQ	....	....	95.61	4.66	....	....	.031	...	...	.002	...	.056	...
Alpha Copper-Tin Alloy, Cold-Drawn	CK	....	....	95.0	5.06	....	....	...	...	...	.01	...	.026	...
Phosphor Bronze, Rolled	F	....	....	95.74	4.20	....	....	...	...	...	.....	...	.048	...
Aluminum Bronze No. 1, Rolled	BJ	....	....	94.85	....	5.62	....	.065	...	...	.....	...	...	...
Aluminum Bronze No. 2, Rolled	BJa	....	....	90.91	None	9.10	....	.002	...	...	None detected	...	...	...
Aluminum Bronze No. 3, Rolled	BJb	....	....	90.52	None	10.01	....	.002	...	...	None detected	...	...	...
Aluminum Bronze No. 4, Rolled	BJc	....	....	87.12	None	10.40	....	2.92	...	...	None detected	...	...	...
Alpha Copper-Zinc Alloy, Cold-Rolled	BP	....	....	71.69	....	....	28.24	0.13	...	...	.017	...	...	...
Alpha Copper-Zinc Alloy, Cold-Drawn	CJ	....	....	73.28	None	....	26.61	.135	...	...	.026	...	...	...
Muntz Metal, Hot-Rolled	BF	....	....	59.65	0.10	....	40.11	.164	...	...	.20	...	...	...
Naval Brass, Hot-Rolled	U	....	....	60.81	0.85	....	38.32	.002	...	...	.002	...	...	...
Manganese Bronze, Hot-Rolled	BG	....	....	58.19	1.04	....	40.10	.65	...	...	.02	...	...	...

Table II
Average Results of Static Tension Tests
Each Value is Average of Two Determinations Except as Indicated

Material	Material Designation	Cooled In	Drawn at Deg. Fahr.	Tensile Strength, Lbs. per Sq. In.	Johnson's Limit, Lbs. Per Sq. In.	Proof Stress, Lbs. Per Sq. In.	Elastic Limit, Lbs. Per Sq. In.	Proportional Limit, Lbs. Per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent
Nickel, Hot-Rolled	AW-1	As Received		×69,100	×20,700	22,500	16,600	×16,500	×53.0	×74.2
Nickel, Hot-Rolled	AW-2	Annealed		×76,200	×30,300	×34,700	27,300	×25,100	×47.0	×69.0
Monel Metal, Cold-Rolled	BK	As Received		×88,500	+	34,500	10,000	+	×28.9	×57.3
Monel Metal, Cold-Rolled	BK-1	□ Annealed		77,100	+	21,300	15,000	+	48.0	64.3
Monel Metal, Cold-Rolled	BH-1	As Received		***97,400	+	41,000	16,500	+	***28.5	***72.2
Monel Metal, Hot-Rolled	AA	As Received		×90,200	×56,200	60,000	51,500	×42,700	×35.9	×69.7
Constantan, Hot-Rolled	CE	As Received		70,500	27,000	28,000	25,000	14,500	48.5	78.3
Copper-Nickel-Chromium Alloy, Forged	D	As Received		97,100	55,500	54,000	35,000	31,000	21.8	46.6
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	As Received		87,300	+	55,500	10,000	+	3.8	22.0
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD	As Received		57,100	+	32,000	21,500	+	35.8	69.8
Copper-Nickel-Alloy, Cold Rolled	B	As Received		49,900	+	30,000	10,000	+	36.0	67.5
Copper, Cold-Rolled	BO	As Received		40,400	+	*13,000	*5,000	+	24.5	66.0
Copper, Hot-Rolled	BU	As Received		***31,400	+	6,500	3,700	+	58.7	72.2
Copper, Cold-Drawn	CL	As Received		40,400	+	19,000	5,000	+	27.0	66.8
Alpha Copper Tin Alloy, Cold Rolled	BQ	As Received		58,600	41,500	*45,000	*15,500	15,500	31.7	71.3
Alpha Copper-Tin Alloy, Cold-Drawn	CK	As Received		62,900	+	25,000	5,000	+	32.5	73.8
Phosphor Bronze, Rolled	F	As Received		***66,400	50,500	***45,500	***32,600	39,000	***21.3	***58.5
Aluminum Bronze No. 1, Rolled	BJ	As Received		×71,900	+	26,800	13,500	+	×42.9	×65.5
Aluminum Bronze No. 2, Rolled	BJa	As Received		×86,800	+	30,500	13,000	+	34.0	54.3
Aluminum Bronze No. 3, Rolled	BJb	As Received		×83,400	***32,000	36,300	27,500	***26,800	***38.5	***39.2
Aluminum Bronze No. 3, Rolled	BJb-1	□ Annealed		62,300	+	21,800	5,000	+	24.3	23.0
Aluminum Bronze No. 4, Rolled	BJc	As Received		***99,000	+	41,800	30,000	+	***30.6	***40.2
Alpha Copper-Zinc Alloy, Cold-Rolled	BP	As Received		47,800	19,000	*20,000	*15,000	15,000	63.5	74.5
Alpha Copper-Zinc Alloy, Cold-Drawn	CJ	As Received		50,400	19,500	21,500	7,500	9,500	57.0	73.0
Muntz Metal, Hot-Rolled	BF-4.8	Iced Brine	480	***76,600	***52,300	49,500	26,000	***26,000	***2.2	***5.2
Muntz Metal, Hot-Rolled	BF-6.5	Iced Brine	650	***79,200	***42,000	43,000	29,500	***28,000	***14.5	***17.2
Muntz Metal, Hot-Rolled	BF-8.4	Iced Brine	840	***65,600	***26,000	27,400	22,000	***20,000	34.5	***42.3
Muntz Metal, Hot-Rolled	BF	□ As Received		***65,100	***31,200	*30,000	*25,000	***23,300	***37.0	***55.4
Naval Brass, Hot-Rolled	U	As Received		×59,300	×18,900	18,300	12,000	×14,700	×47.8	×55.7
Manganese Bronze, Hot-Rolled	BG	As Received		×75,500	+	32,300	16,700	+	×33.5	×44.0

*One determination only.
***Average of three determinations.
×Average of four determinations.
+Stress-strain graphs curved from origin.
□Inserted for comparison only.

Table III
Results of Static Torsion Tests

*One determination only.
**Average of three determinations.
×Average of four determinations.
+Stress-strain graphs curved from origin.
□Inserted for comparison only.

Table III

Results of Static Torsion Tests

Individual Results Except as Indicated

Material	Material Designation	Cooled In	Drawn at Deg. Fahr.	Nominal Torsional Strength, Lbs. Per Sq. In.	Johnson's Limit, Lbs. Per Sq. In.	Proportional Limit, Lbs. Per Sq. In.	Angle of Twist Per Linear In. at Proportional Limit, Minutes	Angle of Twist Per Linear In. at Break, Deg.
Nickel, Hot-Rolled	AW-1	As Received		**71,100	**23,200	**19,500	**13.5	**819
Nickel, Hot-Rolled	AW-2	Annealed		73,400	21,700	19,300	17.0	798
Monel Metal, Cold-Rolled	BK	As Received		65,000	+	+	+	560
Monel Metal, Cold-Rolled	BK-1	□Annealed		67,900	+	+	+	634
Monel Metal, Cold-Rolled	BH-1	As Received		77,300	+	+	+	874
Monel Metal, Hot-Rolled	AA	As Received		**69,000	**31,900	**27,700	**24	**746
Constantan, Hot-Rolled	CE	As Received		66,100	+	+	+	976
Copper-Nickel-Cromium Alloy, Forged	D	As Received		69,700	+	+	+	243
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	As Received		48,000	+	+	+	495
Copper Nickel-Zinc Alloy, Hot-Rolled	CD	As Received		45,300	+	+	+	819
Copper-Nickel Alloy, Cold-Rolled	B	As Received		41,700	+	+	+	753
Copper, Cold-Rolled	BO	As Received		34,000	+	+	+	795
Copper, Hot-Rolled	BU	As Received		29,900	+	+	+	543
Copper, Cold-Drawn	CL	As Received		31,000	+	+	+	759
Alpha Copper-Tin Alloy, Cold-Rolled	BQ	As Received		52,600	+	+	+	810
Alpha Copper-Tin Alloy, Cold-Drawn	CK	As Received		50,700	+	+	+	618
Phosphor-Bronze, Rolled	E							

Cold-Drawn	CF	As Received		48,000	+	+	+	495
Copper Nickel-Zinc Alloy, Hot-Rolled	CD	As Received		45,300	+	+	+	819
Copper-Nickel Alloy, Cold-Rolled	B	As Received		41,700	+	+	+	753
Copper, Cold-Rolled	BO	As Received		34,000	+	+	+	795
Copper, Hot-Rolled	BU	As Received		29,900	+	+	+	543
Copper, Cold-Drawn	CL	As Received		31,000	+	+	+	759
Alpha Copper-Tin Alloy, Cold-Rolled	BQ	As Received		52,600	+	+	+	810
Alpha Copper-Tin Alloy, Cold-Drawn	CK	As Received		50,700	+	+	+	618
Phosphor Bronze, Rolled	F	As Received		55,700	41,000	33,800	48.3	673
Aluminum Bronze No. 1, Rolled	BJ	As Received		52,500	+	+	+	396
Aluminum Bronze No. 2, Rolled	BJa	As Received		59,800	+	+	+	217
Aluminum Bronze No. 3, Rolled	BJb	As Received		44,400	+	+	+	72
Aluminum Bronze No. 3, Rolled	BJb-1	□ Annealed		48,000	+	+	+	91
Aluminum Bronze No. 4, Rolled	BJc	As Received		60,500	+	+	+	60
Alpha Copper-Zinc Alloy, Cold-Rolled	BP	As Received		40,800	13,300	12,100	17	575
Alpha Copper-Zinc Alloy, Cold Drawn	CJ	As Received		42,100	+	+	+	426
Muntz Metal, Hot-Rolled	BF-4.8	Iced Brine	480	54,800	31,400	26,600	60	31
Muntz Metal, Hot-Rolled	BF-6.5	Iced Brine	650	49,800	21,700	19,300	33	99
Muntz Metal, Hot-Rolled	BF-8.4	Iced Brine	840	45,300	16,900	14,500	25	125
Muntz Metal, Hot-Rolled	BF	□ As Received		46,600	17,500	16,900	30	189
Naval Brass, Hot-Rolled	U	As Received		43,000	+	+	+	177
Manganese Bronze, Hot-Rolled	BG	As Received		50,700	+	+	+	96

**Average of two determinations.
+Stress-strain graph is curved from origin.
□Inserted for comparison only.

Material	Material Designation	Cooled In	Drawn at Deg. F.	Aver Tens Stren Lbs. Sq.
1	2	3	4	5
Nickel, Hot-Rolled..	AW-1	As Received		†60,
Nickel, Hot-Rolled..	AW-2	Annealed		†76,
Monel Metal, Cold-Rolled	BH-1	As Received		***97,
Monel Metal, Cold-Rolled	BK	As Received		†88,
Monel Metal, Hot-Rolled	AA	As Received		†90,
Constantan, Hot-Rolled	CE	As Received		70,
Copper-Nickel-Chromium Alloy, Forged	D	As Received		97,
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	As Received		87,
Copper-Nickel-Zinc Alloy, Hot-Rolled.	CD	As Received		57,
Copper-Nickel Alloy, Cold-Rolled	B	As Received		49,
Copper, Cold-Rolled.	BO	As Received		40
Copper, Cold-Drawn.	CL	As Received		40
Copper, Hot-Rolled..	BU	As Received		***31
Alpha Copper-Tin Alloy, Cold-Rolled.	BQ	As Received		58
Alpha Copper-Tin Alloy, Cold-Drawn	CK	As Received		62
Phosphor Bronze, Rolled	F	As Received		***66
Aluminum Bronze No. 1, Rolled....	BJ	As Received		†71
Aluminum Bronze No. 2, Rolled....	BJa	As Received		†80
Aluminum Bronze No. 3, Rolled....	BJb	As Received		†83
Aluminum Bronze No. 4, Rolled....	BJ-c	As Received		***99
Alpha Copper-Zinc Alloy, Cold-Rolled.	BP	As Received		47
Alpha Copper-Zinc Alloy, Cold-Drawn	CJ	As Received		50
Muntz Metal. Hot Rolled	BF-4.8	Iced Brine	480	***76
Muntz Metal. Hot Rolled	BF-6.5	Iced Brine	650	***79
Muntz Metal. Hot Rolled	BF-8.4	Iced Brine	840	***65
Naval Brass. Hot-Rolled	U	As Received		†59
Manganese Bronze, Hot-Rolled	BG	As Received		†75

Each value is average of two specimens
***Three determinations. *One determina
+One determination from 12" gage length
□One determination from 2" gage length
†Four determinations.

Table IV

Relationship of Endurance Limits

To Other Physical Properties

Cooled In	Drawn at Deg. F.	Average Tensile Strength, Lbs. Per Sq. In.	Average Torsional Strength, Lbs. Per Sq. In.	Average Shearing Strength, Lbs. Per Sq. In.	Modulus of Elasticity, Lbs. Per Sq. In.	Endurance Limit Lbs. Per Sq. In. Rotating Cantilever	Endurance Limit Lbs. Per Sq. In. Alternat Torsio
3	4	5	6	7	8	9	10
As Received		†60,100	71,100	49,300	.....	24,000	20,00
Annealed		†76,200	*73,400	56,100	29,400,000	31,500	....
As Received		***97,400	*77,300	67,200	.....	34,000	....
As Received		†88,300	*65,000	61,700	25,000,000	29,000	....
As Received		†90,200	69,000	59,400	25,000,000	38,000	19,00
As Received		70,500	*66,100	*49,400	25,000,000	34,500	....
As Received		97,100	*69,700	61,700	25,000,000	34,000	19,50
As Received		87,300	*48,000	50,900	21,400,000	33,500	....
As Received		57,100	*45,300	*38,300	19,600,000	23,000	....
As Received		49,900	*41,700	35,300	22,000,000	18,000	....
As Received		40,400	*34,000	25,800	20,000,000	.....	6,00
As Received		40,400	*31,000	.....	16,600,000	12,500	....
As Received		***31,400	*29,900	23,900	13,300,000	.....	4,00
As Received		58,600	*52,600	37,000	18,100,000	.....	12,00
As Received		62,900	*50,700	.....	20,000,000	27,000	....
As Received		***66,400	*55,700	43,000	18,200,000	29,000	....
As Received		†71,900	*52,500	53,200	16,600,000	19,000	11,00
As Received		†86,800	*59,800	54,800	15,000,000	24,500	10,00
As Received		†83,400	*44,400	*51,900	17,400,000	29,500	13,00
As Received		***99,000	*60,500	58,200	17,100,000	35,000	17,00
As Received		47,800	*40,800	34,400	16,600,000	.....	9,00
As Received		50,400	*42,100	.....	17,500,000	17,000	....
Iced Brine	480	***76,600	*54,800	55,300	17,800,000	16,000	5,50
Iced Brine	650	***79,200	*49,800	49,700	17,300,000	18,500	7,50
Iced Brine	840	***65,600	*45,300	41,000	16,000,000	18,000	8,50
As Received		†59,300	*43,000	40,800	14,300,000	18,500	....
As Received		†75,500	*50,700	49,400	15,600,000	18,500	....

age of two specimens except as indicated.
ons. *One determination.
from 12" gage length specimen.
from 2" gage length specimen.
ns.

e IV
Endurance Limits
ical Properties

Endurance Limit Lbs. Per Sq. In.		Static Ratios		Endurance Ratios				
Rotating Cantilever	Alternating Torsion	Column 6 to Column 5	Column 7 to Column 5	Column 10 to Column 9	Column 9 to Column 5	Column 10 to Column 5	Column 10 to Column 6	Column 10 to Column 7
9	10	11	12	13	14	15	16	17
24,000	20,000	1.18	0.82	0.83	0.40	0.33	0.28	0.41
31,500	.....	0.96	0.74	...	0.41	...	...	...
34,000	.....	0.79	0.69	...	0.35	...	...	...
29,000	.....	0.74	0.70	...	0.33	...	...	...
38,000	19,000	0.77	0.65	0.50	0.42	0.21	0.28	0.31
34,500	.....	0.94	0.70	...	0.49	...	...	...
34,000	19,500	0.72	0.64	0.57	0.35	0.20	0.28	0.31
33,500	.....	0.55	0.58	...	0.38	...	...	...
23,000	.....	0.79	0.67	...	0.40	...	...	...
18,000	.....	0.84	0.71	...	0.36	...	...	...
.....	6,000	0.84	0.64	0.48	...	0.15	0.18	0.24
12,500	.....	0.77	...		0.31	...	...	...
.....	4,000	0.95	0.76	...	...	0.13	0.13	0.17
.....	12,000	0.90	0.63	0.44	...	0.21	0.23	0.32
27,000	.....	0.81	...		0.43	...	...	...
29,000	.....	0.84	0.65	...	0.44	...	...	...
19,000	11,000	0.73	0.74	0.58	0.26	0.16	0.21	0.21
24,500	10,000	0.69	0.63	0.41	0.28	0.11	0.17	0.18
29,500	13,000	0.53	0.62	0.44	0.35	0.16	0.29	0.25
35,000	17,000	0.61	0.59	0.48	0.35	0.17	0.28	0.29
.....	9,000	0.85	0.72	0.53	...	0.19	0.22	0.26
17,000	.....	0.84	...		0.34	...	...	...
16,000	5,500	0.72	0.72	0.34	0.21	0.07	0.10	0.10
18,500	7,500	0.63	0.63	0.41	0.23	0.09	0.15	0.15
18,000	8,500	0.69	0.62	0.47	0.27	0.12	0.19	0.21
18,500	.....	0.73	0.69	...	0.31	...	...	...
18,500	.....	0.67	0.65	...	0.24	...	...	...

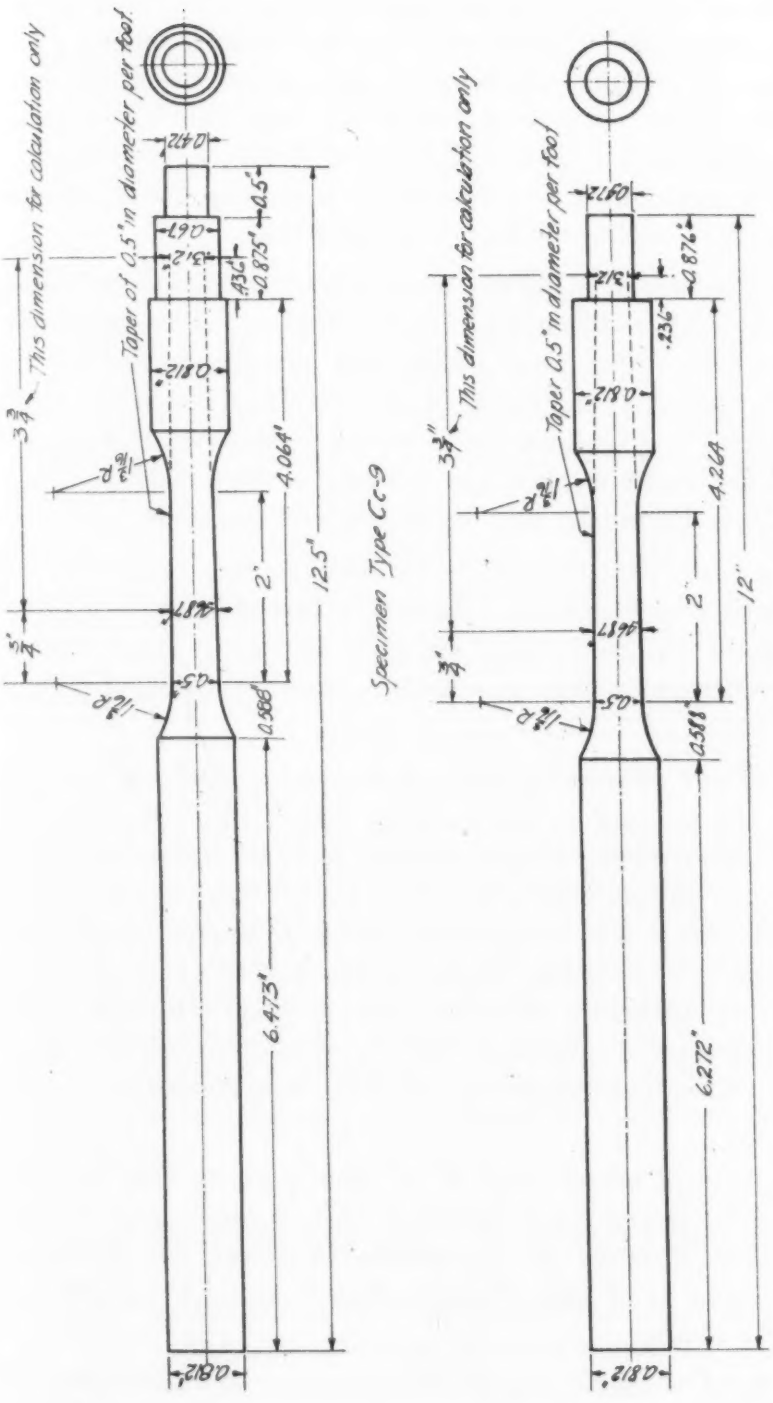

This dimension for calculation only
Taper of 0.5" in diameter per foot
Specimen Type C-9
This dimension for calculation only
Taper 0.5" in diameter per foot
Specimen Type C-9

Fig. 1—Dimensions of Rotating Cantilever Endurance Test Specimens

Fig. 1 shows the form used with a large end bearing for testing heat treated alloy steels. The lower sketch shows the form that may be used with smaller bearing for testing metals of lower strength. The taper of this specimen is so designed that the maximum stress is about ¾ inches out from the fillet and over a length of about 1½ inches the stress does not vary more than about 1½ per cent. A specimen of this type breaks somewhere in the conical surface, never in either fillet.

The method of polishing the rotating specimens by means of a cloth-covered rotating disk and cylinder has been previously described (4). The final polish was always in a longitudinal direction and was continued until no circumferential scratches were visible at a magnification of 50 diameters. The types of finish of the various specimens are as described below. The type of finish is indicated by number on each of the stress-cycle graphs.

Finish 9: Finishing tool, ½ inch radius. Speed of lathe, 90 revolutions per minute. Feed 130 threads per inch, No. 000 emery cloth, longitudinally, about 3 minutes; flour of emery, circumferentially, about 3 minutes; flour of emery, longitudinally, about 3 minutes.

Finish 13:—Finishing tool, $\frac{1}{16}$ inch to ⅛ inch radius. Speed of lathe, 165 revolutions per minute. Feed 130 threads per inch. No. 000 emery cloth, longitudinally, 5 to 15 minutes; No. 000 emery cloth, circumferentially, 5 to 15 minutes; flour of emery, circumferentially, 5 to 15 minutes; flour of emery, longitudinally, 5 to 15 minutes; levigated alumina, No. 1, circumferentially, 5 to 15 minutes; levigated alumina, No. 1, longitudinally, 5 to 15 minutes; levigated alumina, No. 2, circumferentially, about 5 minutes; levigated alumina, No. 2, longitudinally, about 5 minutes.

The flour of emery used is of such a grade that it stays in suspension in water for 2 minutes. No. 1 alumina was of such fineness that it stays in suspension in water for 40 minutes. No. 2 alumina is of such fineness that it stays in suspension in water for 3 hours.

The machine used was of the improved White-Souther Type (1,4). With this machine the specimen can be adjusted so that vibration is negligible.

The results of rotating-cantilever tests are illustrated in Figs. 2 to 8 inclusive by stress-cycle graphs on a semi-logarithmic scale. In these graphs the center of each small circle represents the result obtained with a single test specimen. The majority of the

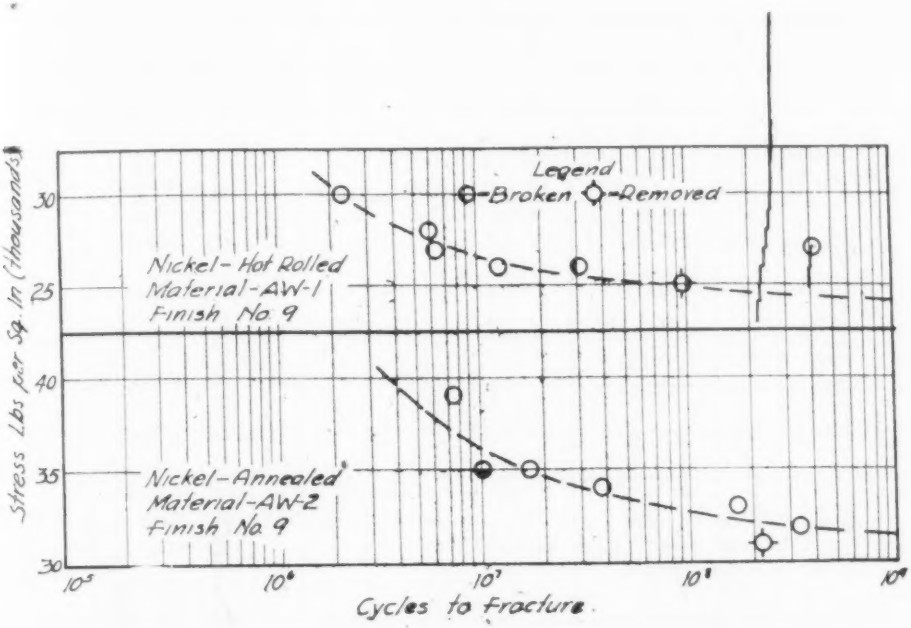


Fig. 2—Graphs Showing Rotating Cantilever Results on Nickel.

specimens were tested at constant bending moment and hence at constant nominal stress. In some specimens, however, the stress was not held constant but was increased at intervals. The result of such a test is represented by a solid zigzag line with circle at its upper end. The lower end of the line represents the point at which the first increase of stress was made, each vertical portion of the line represents an intentional increase of stress, and each horizontal portion represents the number of cycles endured at the indicated stress.

Results of Rotating-Cantilever Tests of Nickel and Its Alloys

Results of rotating-cantilever endurance tests of nickel are illustrated by Fig. 2. Through the experimentally determined points for each material a broken line has been drawn to represent the average stress-cycle relationship. Although there is no evidence that either graph has become horizontal even at several

hundred million cycles, the slope of each graph beyond two hundred million cycles has become so slight as to indicate within a rather narrow range the probable position of the endurance limit for one billion cycles. Additional evidence that the graphs beyond

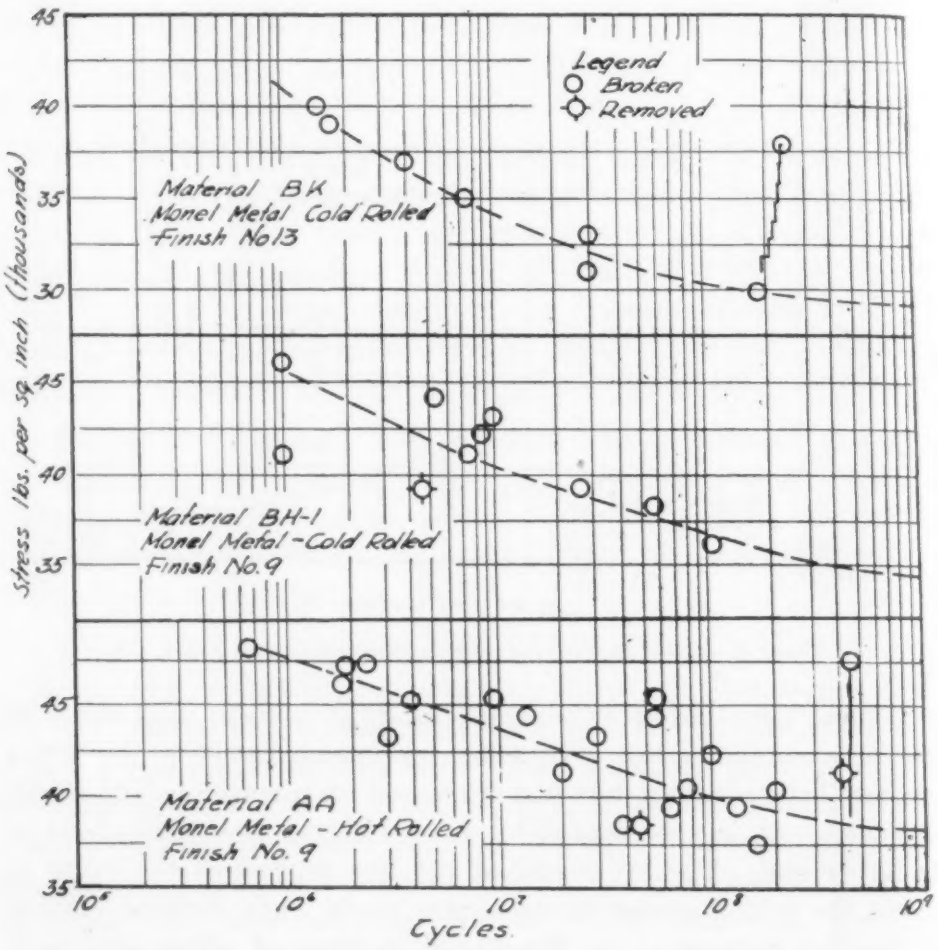


Fig. 3—Graphs Showing Rotating Cantilever Results on Monel Metal.

200,000,000 cycles are approaching the horizontal direction is afforded by the behavior of two specimens of material AW-1. These two specimens after enduring more than 200,000,000 and 400,000,000 cycles respectively were still so far from failure that they withstood considerable increases of stress before fracture. One of these specimens was apparently strengthened by the endurance test of more than 200,000,000 cycles at a stress of 23,000 pounds per square inch, since it afterwards withstood repeated increases of stress before it finally failed at a stress that if applied

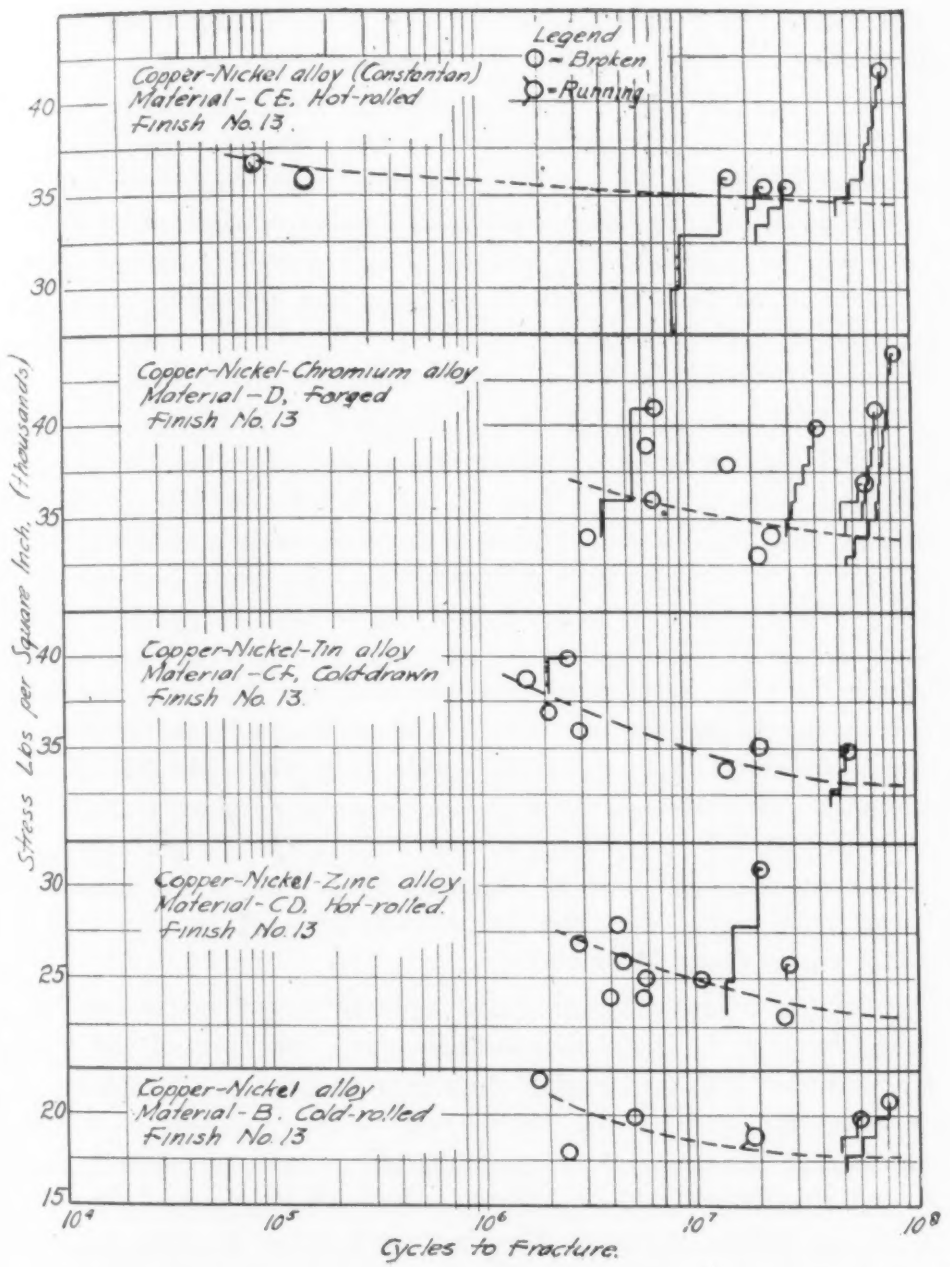


Fig. 4—Graphs Showing Rotating Cantilever Results on Nickel and Some Nickel Alloys.

to a new specimen would have caused failure in less than one million cycles. The increases were in steps of 1000 pounds per square inch and at each of these steps the specimen endured from 2,000,000 to 11,000,000 cycles. It seems probable, therefore, that if

the stress had not been raised, these two specimens would have endured more than a billion cycles without failure.

If from the end of the experimentally determined portion of each curve a tangent be extended to the right, it would reach an abscissa of one billion cycles at a point only slightly below the curve as drawn. It seems probable, however, that slight curvature of the idealized stress-cycle graph should continue to an abscissa of at least one billion cycles. The endurance limits for one billion cycles, for material AW-1 and AW-2 respectively, are approximately 24,000 and 31,500 pounds per square inch.

It will be noted that the endurance limit for the annealed nickel is higher than the endurance limit for the "as-rolled" material. As listed in Table II the tensile strength of the annealed material is also higher than that of the material "as-rolled." This perplexing difference in properties between "as-rolled" and annealed material has finally been ascribed to variations in the physical properties of the material from various bars of the lot. The specimens first annealed are not from the same bar as the specimens as rolled. Annealed specimens from some other bars show about the same tensile strength as the "as-rolled" material. Brinell tests from the various bars either as rolled or annealed varied more than 30 per cent. The Brinell hardness of the six annealed bars as obtained with the 500 kilogram load varies from 57 to 80; the Brinell hardness of the six bars as rolled varies from 80 to 109.

Results of rotating-cantilever tests of monel metal are illustrated by Fig. 3. As shown in this figure, the slope of the graph for material BK apparently decreases rapidly with increase of the abscissa beyond about 200,000,000 cycles. One specimen after running at the original stress of 31,000 pounds per square inch for nearly 200,000,000 cycles was subjected to repeated increases of stress before failure. The increases were in steps of 1000 pounds per square inch, and during the increases the specimens endured about 90,000,000 cycles. This specimen, if the stress had not been raised, would undoubtedly have endured more than a billion cycles without failure. The short experimentally determined portion of the graph for material BH-1 shows no evidence of an endurance limit. It seems probable, however, that beyond 200,000,000 cycles the slope of this graph would decrease rapidly

as does the slope of the graphs of material BK. The graph for material AA evidently becomes nearly horizontal beyond 200,000,000 cycles. Two specimens of this material endured more than 400,000,000 cycles without failure and one of these specimens then endured repeated increases of stress. The increases were in

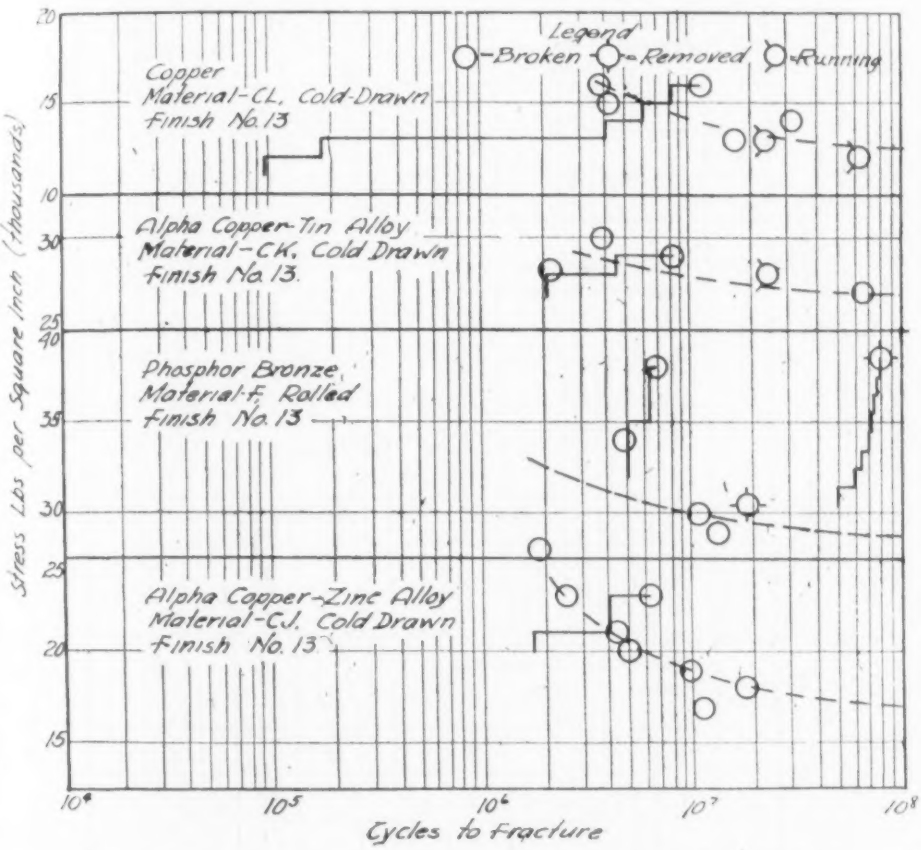


Fig. 5—Graphs Showing Rotating Cantilever Results on Copper and Some Alpha Alloys.

steps of 1000 pounds per square inch and at each of these steps the specimen endured about 2,000,000 cycles. Evidently therefore the average endurance limits of these three materials are represented approximately by the points at which the three broken line curves cross the ordinate at one billion cycles.

Fig. 4 shows results of rotating-cantilever tests of various alloys of nickel. As shown in the upper graph, "Constantan" gives an unusually flat stress-cycle graph. Five specimens failed at stresses of 35,500 to 37,800 pounds per square inch. One specimen which was started at 34,000 pounds per square inch endured

50,000,000 cycles at this stress and afterward endured 30,000,000 cycles at repeatedly increased stresses.

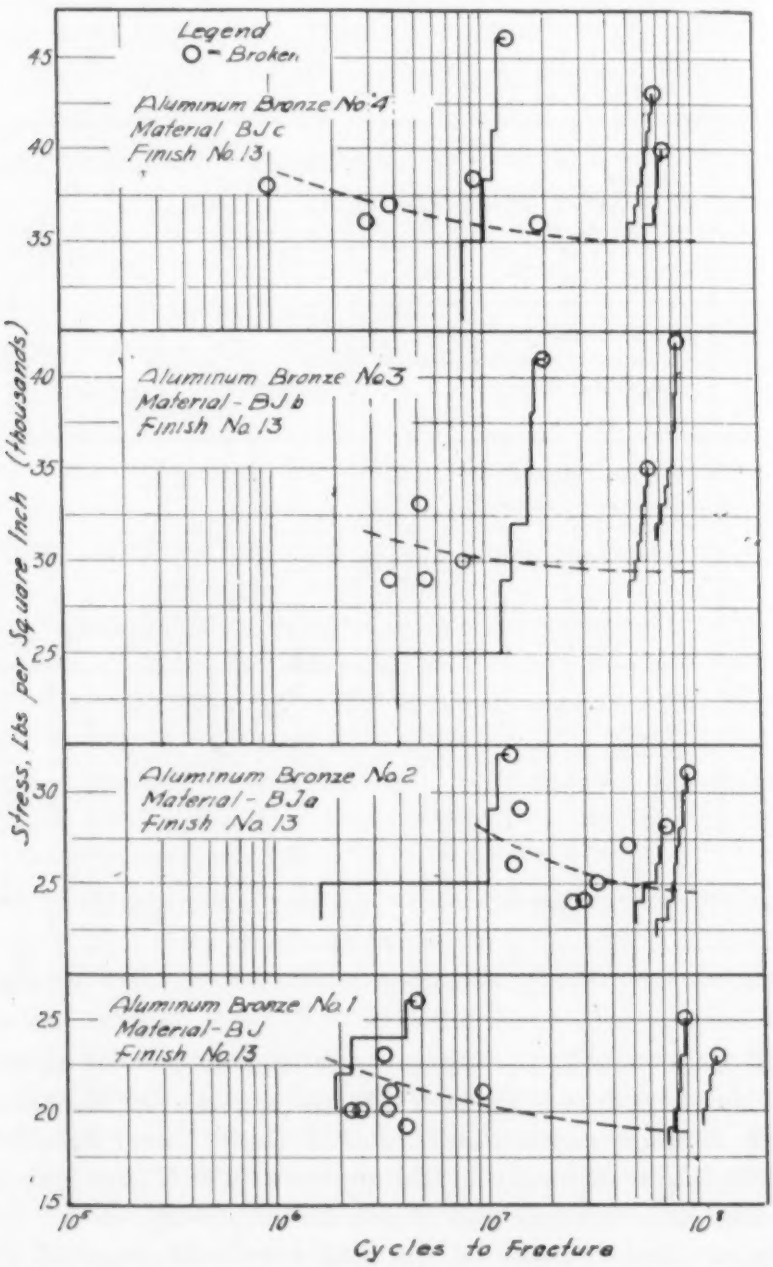


Fig. 6—Graphs Showing Rotating Cantilever Results on Aluminum Bronzes.

The copper-nickel-chromium alloy, material D, gave variable results. The range of endurance properties of various specimens is equivalent to a variation of about 5000 pounds per square inch

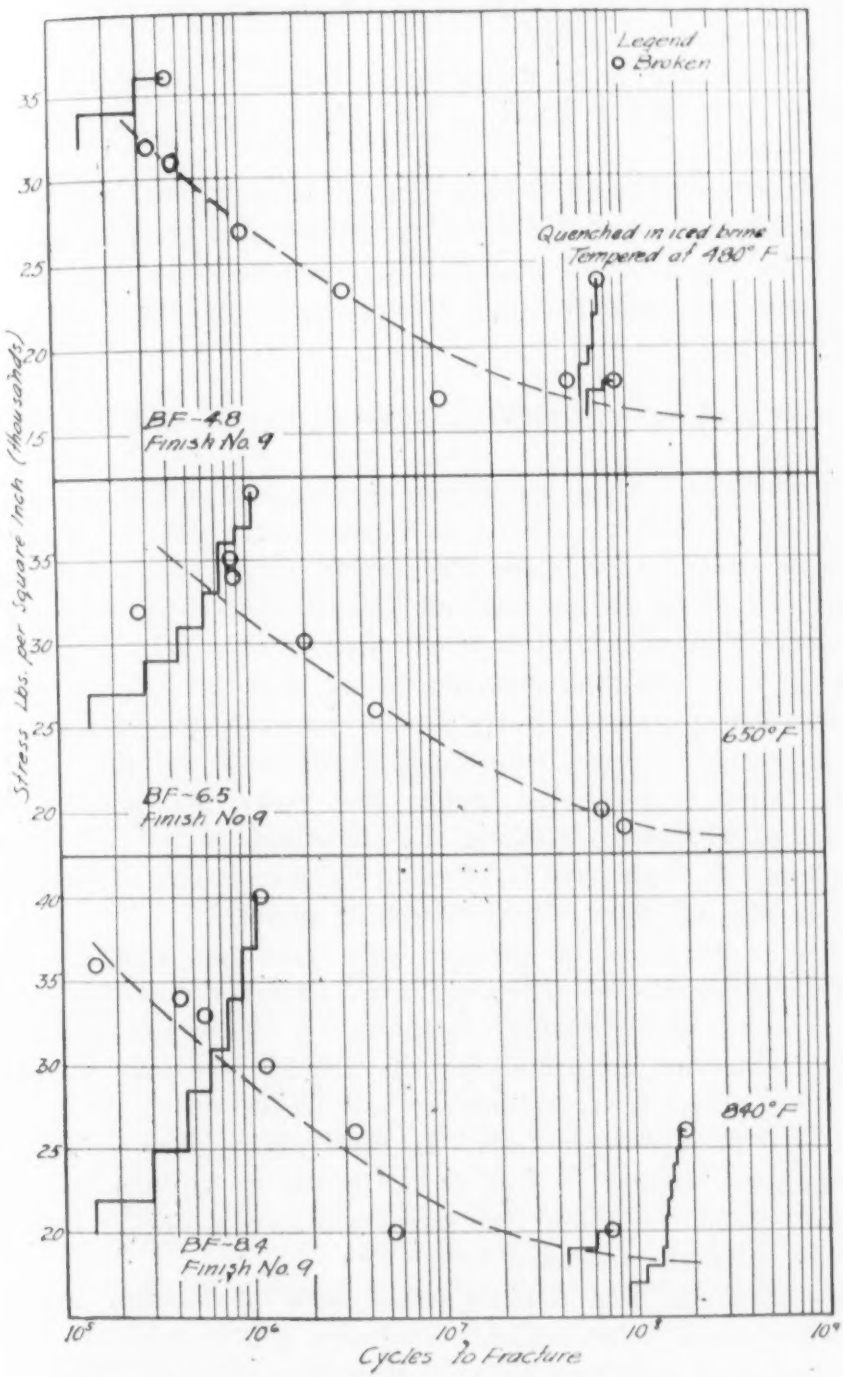


Fig. 7—Graphs Showing Rotating Cantilever Results on Muntz Metal.

in the endurance limit. This alloy contains numerous small hard particles of a chromium constituent which may account for the

irregularity of results. Such irregularity, however, is not uncommon in non-ferrous alloys.

Material CF is an alpha solid-solution of nickel and tin in copper. This alloy as shown in Fig. 4 gives a fairly regular stress-cycle curve.

Materials CD and B each contain about 20 per cent nickel. The results for material B are more regular than those for material CD. One specimen of material B, however, broke prematurely. This specimen was running at approximately the "endurance limit" stress.

Results of Rotating-Cantilever Tests of Copper and Its Alloys

Results of rotating-cantilever tests on copper and some of its alpha alloys with tin and zinc are illustrated by Fig. 5. As shown in these graphs the average stress-cycle curves evidently become nearly horizontal at abscissas of 10,000,000 to 20,000,000 cycles. Material CK as shown by chemical analysis is actually a phosphor bronze. The individual results obtained with material CJ are so regular that they show clearly the form of the stress-cycle graph. One specimen, however, running at about the "endurance limit" stress, failed to reach the broken line graph. Such premature failures of specimens tested at the endurance limit are frequent. Many other examples will be revealed by examination of the stress-cycle graphs of alloys of nickel and of copper.

Fig. 6 shows results obtained with aluminum bronze of four different compositions. The graphs are arranged from top to bottom in order of decreasing aluminum (or aluminum plus iron) content. The first endurance test on each of these four aluminum bronzes was merely a preliminary test to determine the stresses to be used in subsequent tests. In these preliminary tests, which are readily identified in Fig. 6, the initial stress was below the probable endurance limit; the stress was then raised at frequent intervals until the specimen broke.

As shown in Fig. 6 there is for each of the four kinds of material a stress below which a specimen will apparently endure indefinitely and may even be strengthened by the test. At stresses only slightly higher a specimen breaks after comparatively few cycles. It has been observed that at a stress just above the "endurance limit" a specimen will often break after fewer cycles

than will a specimen tested at higher stresses. There are, therefore, definite endurance limits for all four kinds of aluminum bronze. These may be determined approximately by individual tests of not more than 25,000,000 cycles.

Fig. 7 shows results obtained with heat treated Muntz metal. The Muntz metal was quenched and drawn at three different tem-

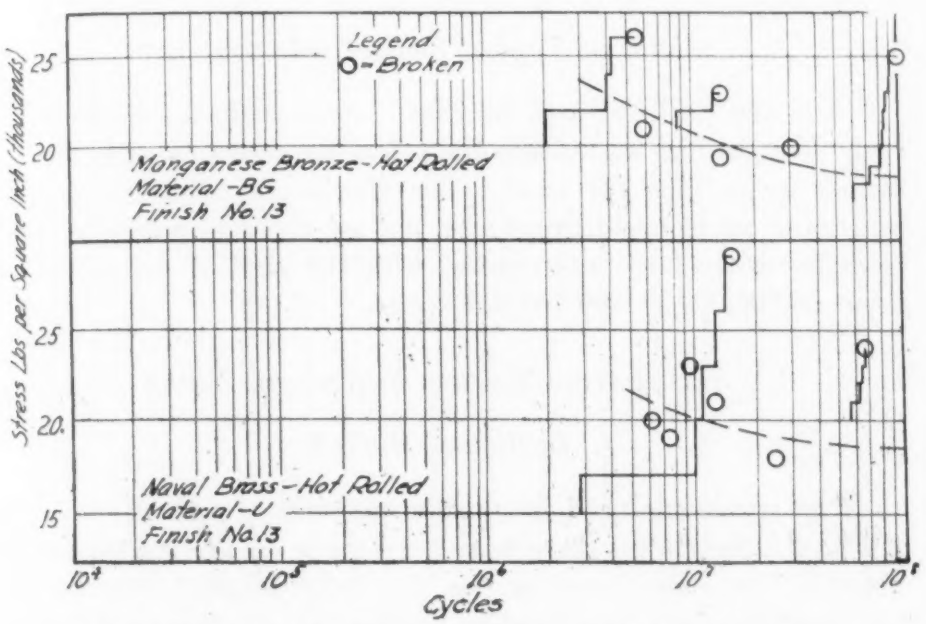


Fig. 8—Graphs Showing Rotating Cantilever Results on Copper Alloys.

peratures. As shown in this figure, the slope of each graph out to an abscissa somewhere between 10,000,000 and 100,000,000 is very steep. For materials BF-4.8 and BF-8.4 as the stress is lowered a point is reached at which the results are exceedingly variable. At a stress slightly above this point a specimen may fail after a few million cycles. At a stress slightly below this point a specimen apparently will endure many million cycles and fail only after repeated increases of stress. It seems probable that a similar phenomenon would have been observed with material BF-6.5 if additional tests could have been made at a stress of about 18,000 to 21,000 pounds per square inch.

The endurance limits of all three materials represented in Fig. 7 are about the same as that of Muntz metal as rolled. Increasing the tensile strength of Muntz metal by heat treatment apparently does not increase the endurance limit.

Fig. 8 shows results obtained with rolled Naval brass and manganese bronze. As indicated in this figure the broken line curves representing average stress-cycle relationship evidently become nearly horizontal beyond an abscissa of about 25,000,000 cycles. The endurance limit for the manganese bronze is slightly higher than that obtained by R. R. Moore. His material, however, was cast manganese bronze of slightly lower tensile strength.

Shape of Typical Stress Cycle Graphs

The results illustrated in Figs. 2 to 8 inclusive indicate that there is a definite endurance limit for the alloys of nickel and of copper as well as for steel. The abscissa at which a rotating-cantilever stress-cycle graph for one of these non-ferrous alloys becomes nearly horizontal varies, with the kind of material, from about 20,000,000 to 200,000,000 cycles.

Alternating-Torsion Endurance Tests

Outline of Method

The specimens used in alternating-torsion tests are as shown in Fig. 9. Nearly all these tests were made on the machine of the "inertia" type developed at the Naval Experiment Station (13). The short specimen was used in earlier tests on this machine (4). Recent tests have been made by the "accelerated-fatigue" method (11), in which the two longer specimens have been used. With these long specimens the amplitude of oscillation of the flywheel due to twist of the specimen is a large proportion (often three-fourths) of the total amplitude of oscillation. Under these conditions any weakening of the specimen during an endurance test results in automatic increase in the amplitude of oscillation of the flywheel and hence in automatic increase of the torsional moment. The gradual automatic increase in the stress accelerates the failure of the specimen.

Typical Results

Fig. 10 illustrates the results obtained by the "accelerated-fatigue" method. Each line in the figure represents the course of an accelerated-fatigue test of one specimen. Intentional increases of stress are indicated by arrow tips; all other increases were

automatic. It will be noted that the steepness of the slope of these lines decreases as the stress is lowered until at a stress of about 21,000 pounds per square inch a specimen endures about five million cycles before failure. Experience has shown that,

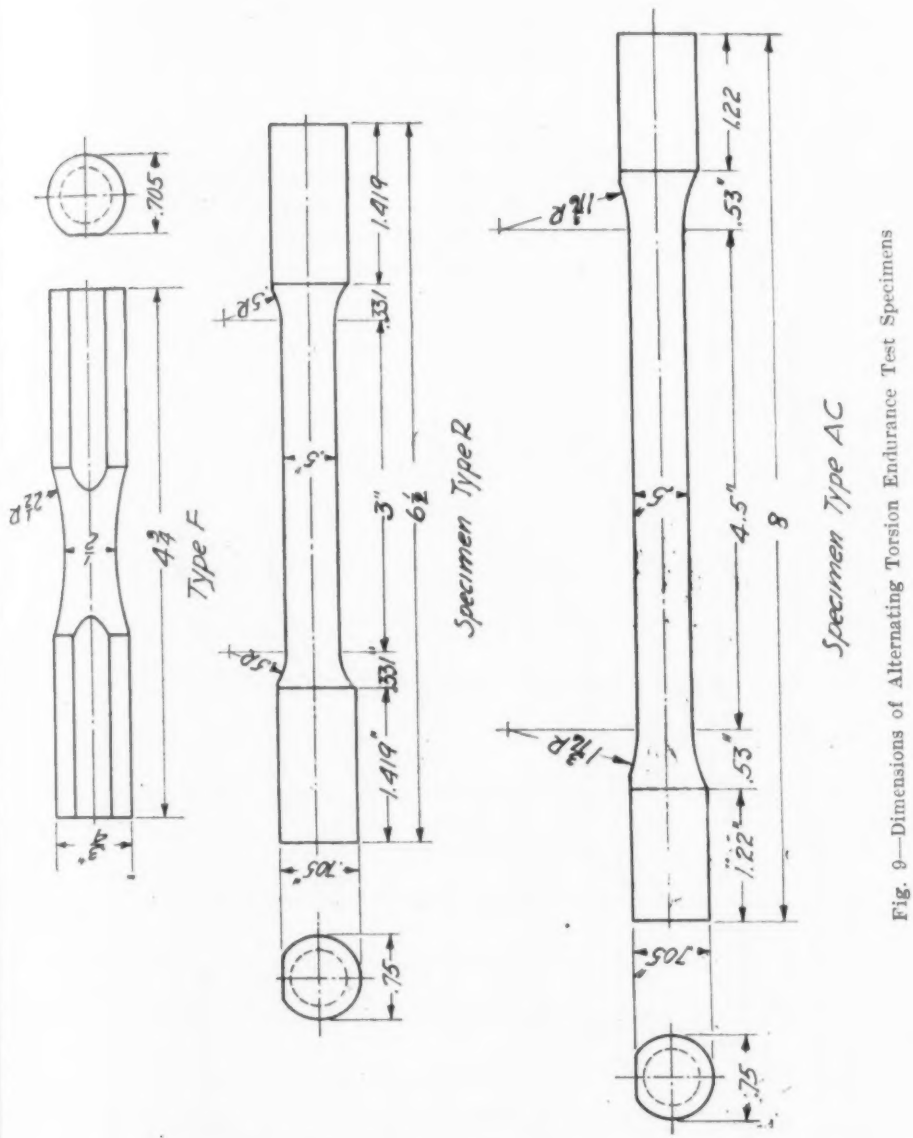


Fig. 9—Dimensions of Alternating Torsion Endurance Test Specimens

when the stress remains at or near the initial value for about five million cycles, this stress is not far above the endurance limit of the material.

Figs. 11 to 13 inclusive show results obtained by the acceler-

ated-fatigue method with aluminum bronze of three compositions. As shown in Fig. 11 a specimen started at a stress of abou

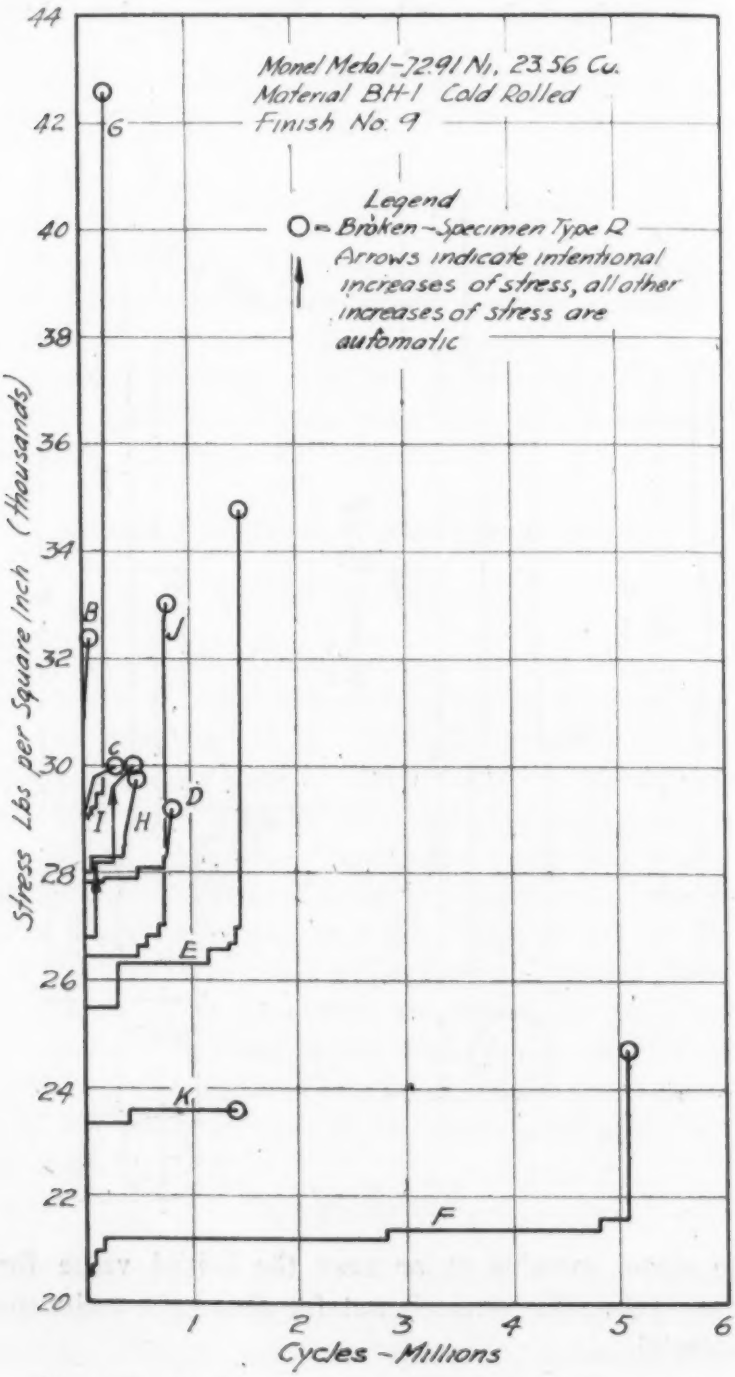
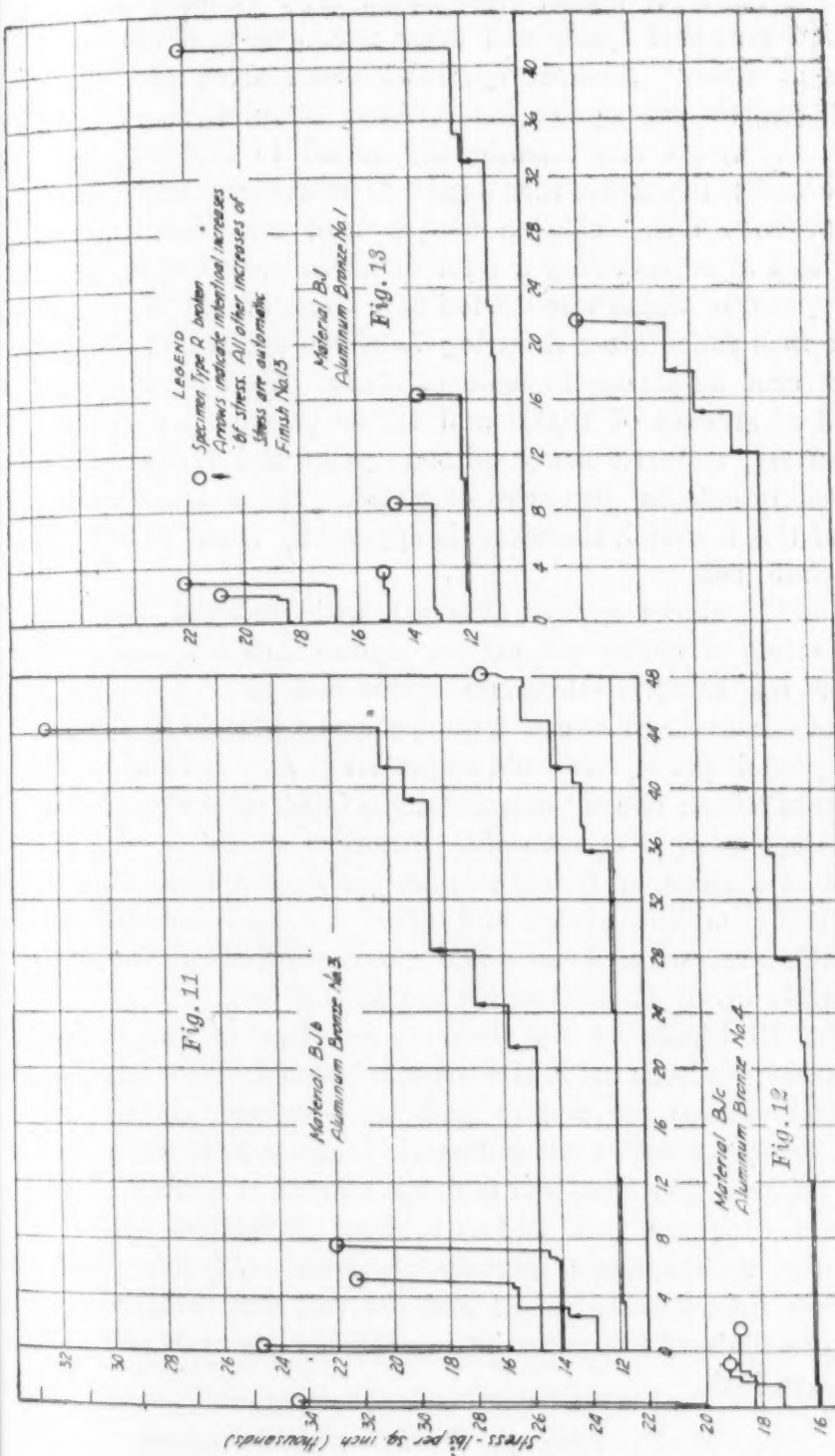


Fig. 10—Graphs Showing Alternating Torsion Results on Monel Metal.



Figs. 11, 12 and 13—Graphs Showing Alternating Torsion Results on Aluminum Bronzes

16,000 pounds per square inch failed after running only a few hundred thousand cycles and after a 50 per cent automatic increase of stress. Another specimen was started at a stress of 13,000 pounds per square inch. After running about 2,500,000 cycles, the stress was intentionally raised to 14,000 pounds per square inch; the stress then began to increase automatically and the specimen failed after a 50 per cent automatic increase of stress and after enduring a total of about 5,000,000 cycles. Another specimen which was started at a stress of 14,000 pounds per square inch failed after enduring 7,000,000 cycles and after about 50 per cent automatic increase of stress. Two other specimens, started at stresses of 15,000 and 12,000 pounds per square inch respectively, endured many million cycles and failed only after repeated intentional increases of stress. The average endurance limit of this material, therefore, is apparently about 13,000 pounds per square inch.

Fig. 12 shows results obtained with material BJc. With initial stress of 20,000 pounds per square inch a specimen failed after a few hundred thousand cycles and after a 70 per cent automatic increase of stress. Two specimens, started at 17,000 and 18,000 pounds per square inch, respectively, soon showed automatic increase of stress; one of these specimens failed after about 5,000,000 cycles, the other was removed. Another specimen, which was started at a stress of 16,000 pounds per square inch, failed only after many million cycles and after repeated intentional and automatic increases of stress. The endurance limit of this material is probably about 17,000 pounds per square inch.

Fig. 13 illustrates the decrease in slope of the individual stress-cycle graphs as the initial stress is lowered. With initial stress of 12,000 pounds per square inch the specimen endured about 16,000,000 cycles with little automatic increase in stress until just before failure. The specimen that was started at a stress of 11,000 pounds per square inch endured about 33,000,000 cycles with practically no automatic increase of stress. At this point the stress was intentionally raised and the test was continued. The endurance limit of this material is probably about 11,000 pounds per square inch.

Results Recorded on Semi-Logarithmic Scale

Results shown in graphs such as those in Figs. 10 to 13

inclusive may also be shown in simplified form on a semi-logarithmic scale. In so representing results of accelerated-

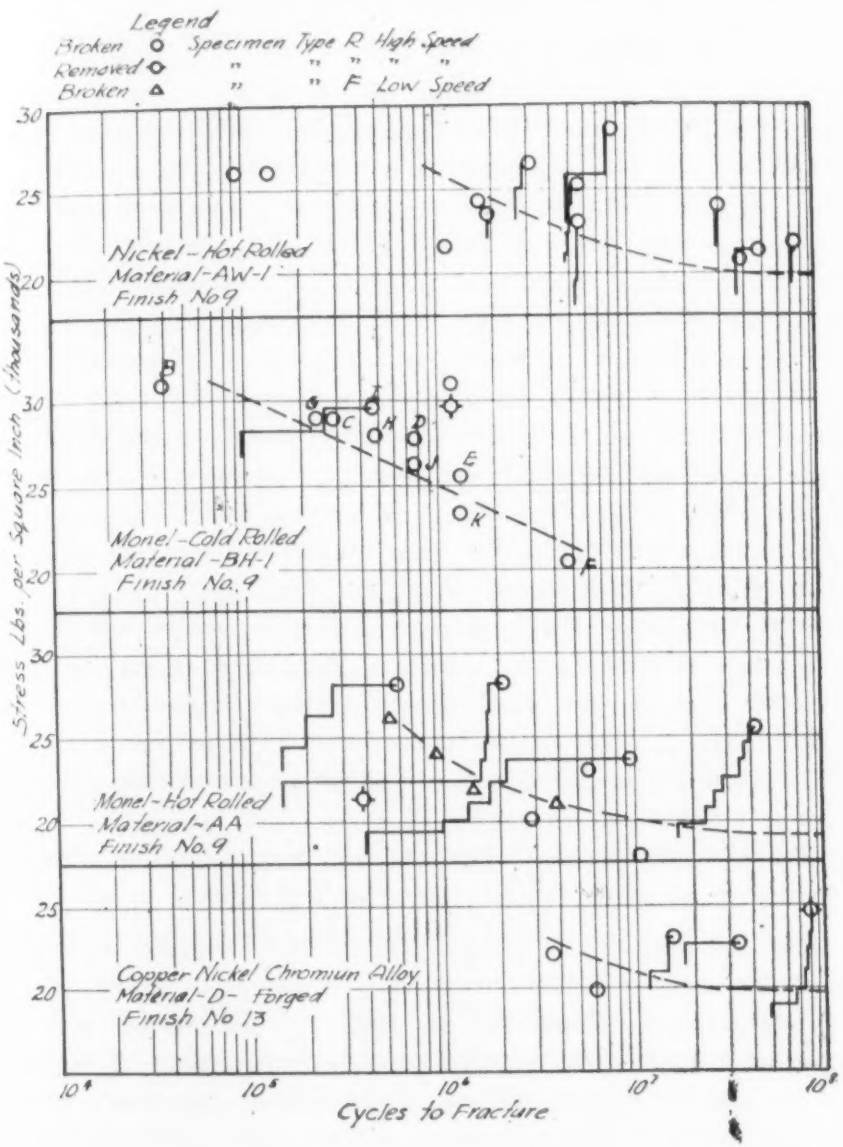


Fig. 14—Graphs Showing Alternating Torsion Results on Nickel and Some Nickel Alloys.

fatigue tests all automatic increases of stress are disregarded and only original stresses and intentional increases are plotted: For example, the results recorded in Fig. 14 for monel metal, material BH-1, represent the individual tests that are designated by the

same letters in Fig. 10. In the same manner the results obtained with aluminum bronze as shown in Figs. 11 to 13 inclusive are represented on a semi-logarithmic scale in Fig. 15.

Fig. 14 represents in this manner alternating-torsion results obtained with nickel and some of its alloys. The upper graph shows results obtained with hot-rolled nickel, the same material that gave the rotating-cantilever results shown in Fig. 2. As shown in this graph, specimens tested at a stress of about 26,000 pounds per square inch failed after comparatively few cycles, whereas specimens started at a stress of less than 20,000 pounds per square inch endured many million cycles and failed only after intentional increases of stress, and automatic increases not shown in the figure. There is considerable difference between the endurance properties of the individual specimens; a similar range of properties of the material was observed in the rotating-cantilever results. The broken-line curve represents the estimated average stress-cycles relationship for this material. Fig. 14 also shows results obtained with monel metal, material AA. This is the same material that gave the rotating-cantilever results shown in the lower graph of Fig. 3. As shown in Fig. 14, with an initial stress of 26,000 pounds per square inch failure occurred after about 500,000 cycles. With an initial stress of 19,000 pounds per square inch a specimen endured a total of about 45,000,000 cycles with frequent intentional increases of stress, and automatic increases not shown in the figure. The average stress-cycle relationship is probably about as represented by the broken-line curve.

Fig. 14 also shows alternating-torsion results obtained with the same copper-nickel-chromium alloy that gave rotating-cantilever results illustrated in Fig. 4. As shown in Fig. 14 specimens tested with initial stress of more than 20,000 failed after comparatively few million cycles. One specimen tested with initial stress of 18,000 pounds per square inch endured 50,000,000 cycles and then endured 30,000,000 more cycles at gradually increasing stress. It should be emphasized that the actual stress throughout a large part of this test was considerably higher than the value indicated. As explained above, automatic increases of stress are not indicated in semi-logarithmic representation of results obtained by the accelerated-fatigue method.

Fig. 15 shows results obtained with copper and the "alpha"

alloys of copper with tin and zinc respectively. The upper two graphs show results obtained with cold and hot-rolled copper respectively. The cold-rolled copper with an initial stress of 9000 pounds per square inch failed after a comparatively short test. As the stress was lowered in successive tests the number of

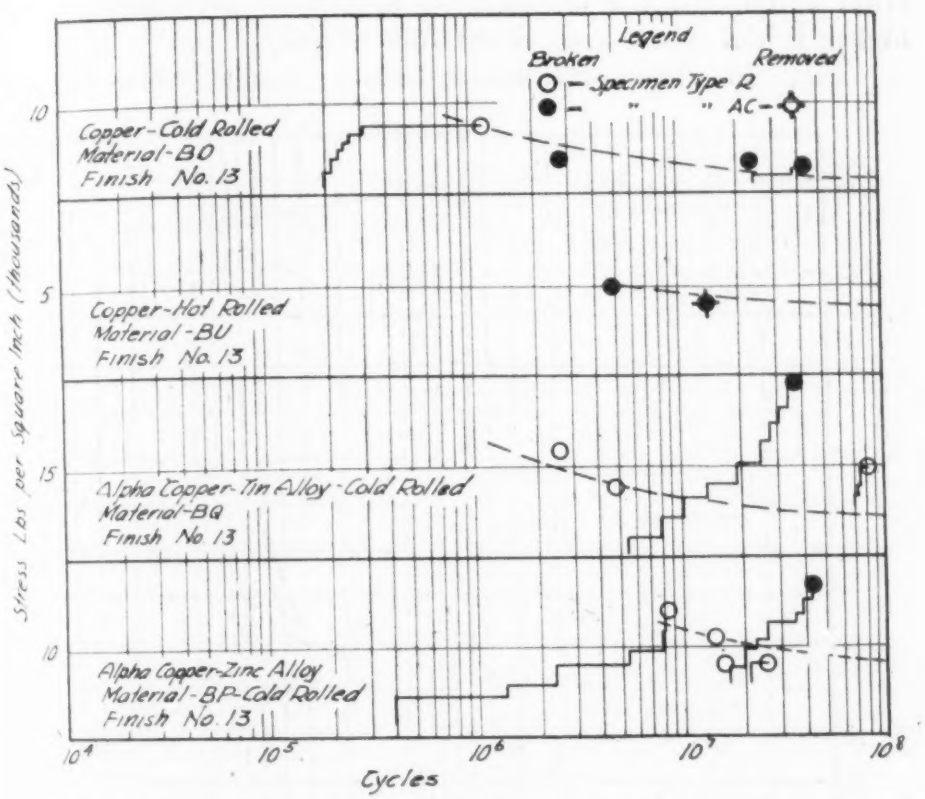


Fig. 15—Graphs Showing Alternating Torsion Results on Copper and Some Alpha Alloys.

cycles endured increased rapidly. The average stress-cycle relationship may evidently be represented by a line that becomes nearly horizontal at an abscissa of about ten million cycles.

Fig. 15 also shows results obtained with cold-rolled alpha-bronze. This material with an initial stress of about 15,000 pounds per square inch failed after a few million cycles. With an initial stress of 12,500 pounds per square inch it endured about 70,000,000 cycles and then failed only after repeated intentional and automatic increases of stress.

As shown in the bottom graph of Fig. 15, specimens of alpha-brass when tested with initial stress of more than 9000 pounds

per square inch failed after not more than 15,000,000 cycles. With initial stress of 8000 pounds per square inch, however, a specimen endured more than 40,000,000 cycles with repeated intentional and automatic increase of stress. An initial stress of 8000 pounds per square inch, therefore, is a critical stress for this material. With lower initial stress a specimen is apparently strengthend; with higher initial stress a specimen fails rapidly.

Fig. 16 shows alternating-torsion results obtained with

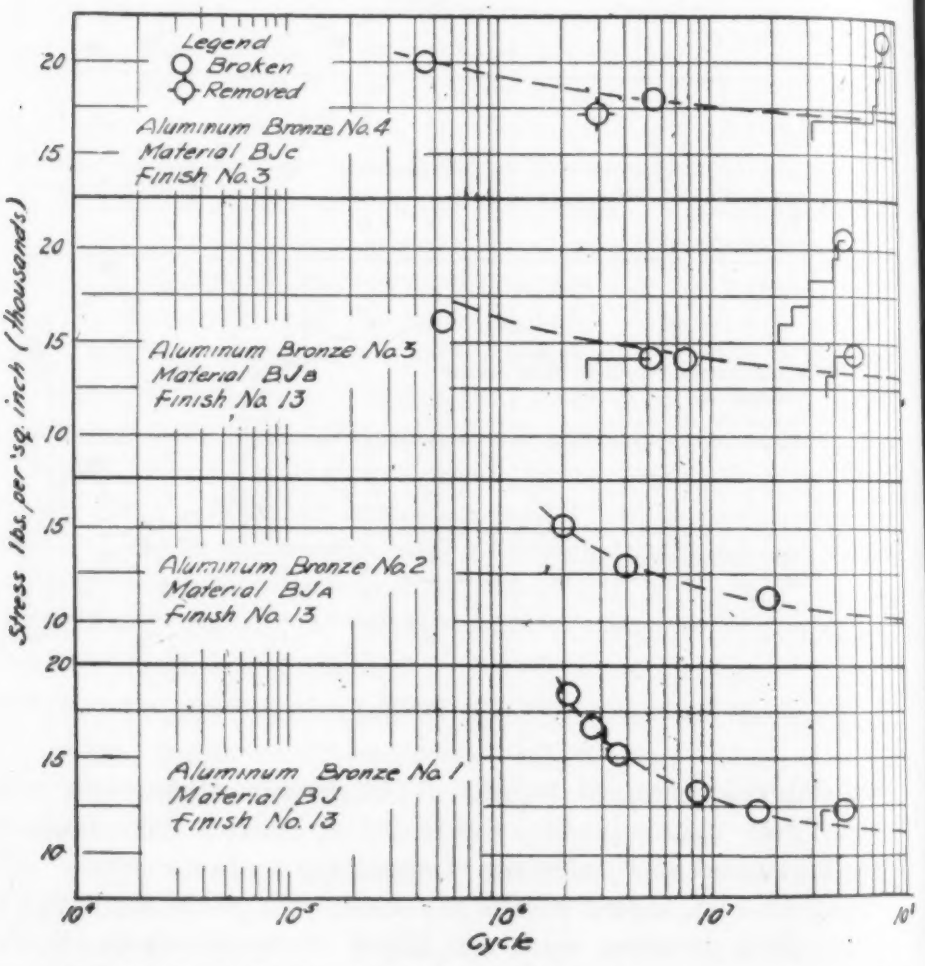


Fig. 16—Graphs Showing Alternating Torsion Results on Aluminum Bronzes. Specimen—Type R.

aluminum bronzes of four compositions. The same results for three of these bronzes are represented more completely in Figs. 11 to 13 inclusive. In Fig. 16 the automatic increases in stress shown in Figs. 11 to 13 have been disregarded in plotting the results. It

will be observed that the results obtained with material BJ indicate with unusual definiteness the form of the ideal stress-cycle graph. It is seldom that so uniform a series of results is obtained. It will be observed also that the radius of curvature increases from the lower to the upper graph of Fig. 16. Rotating-cantilever results with these same aluminum bronzes are shown in Fig. 6.

Fig. 17 shows alternating-torsion results obtained with heat-treated Muntz metal. Rotating-cantilever results obtained with

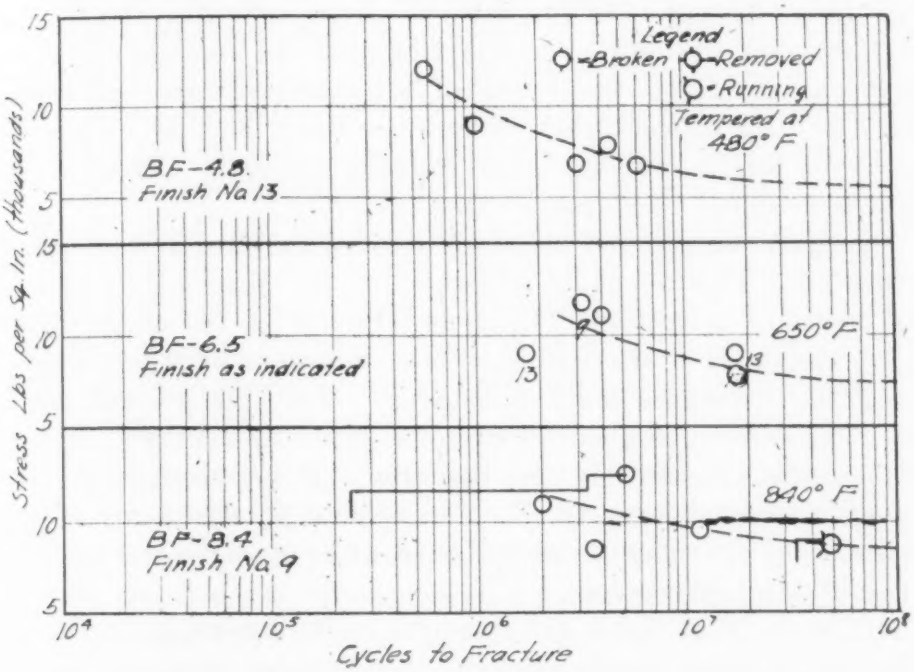


Fig. 17—Graphs Showing Alternating Torsion Results on Muntz Metal. Specimen—Type R.

the same material are shown in Fig. 7. As shown in Fig. 17 the endurance limit for the material drawn at lowest temperature is no higher than that for the material drawn at highest temperature. This confirms the results obtained by the rotating-cantilever method.

It will be observed that in each of the alternating-torsion graphs, Figs. 14 to 17 inclusive, the line representing average stress-cycle relationship becomes nearly horizontal at a smaller abscissa than in the corresponding rotating-cantilever graph. This difference in form between the alternating-torsion and rotating-cantilever graphs is probably due in part to fatigue-acceleration.

There is some evidence, however, that the difference is not due entirely to fatigue-acceleration.

Endurance Ratios

The endurance limits as estimated from the above described stress-cycle graphs of alloys of nickel and of copper are assembled in columns 9 and 10 of Table IV. In columns 5 to 8 of the same table are assembled the corresponding values for tensile strength, torsional strength, shearing strength and modulus of elasticity. In columns 11 and 12 of this table are listed the ratios of torsional and shearing strength to tensile strength. In columns 13 to 17 inclusive are listed the ratios of alternating-torsion endurance limit to rotating-cantilever endurance limit, and of endurance limits to tensile, torsional and shearing strength. These ratios have been called "endurance ratios" (4, 7).

As previously stated the nickel was not uniform in its physical properties. This no doubt accounts for the abnormal ratios for this material in columns 11, 12 and 13. With the exception of nickel the ratios of alternating-torsion endurance limit to rotating-cantilever endurance limit as listed in column 14 average about 0.5. The values for shearing strength, given in column 7, are for some metals considerably less than the correpsonding values for nominal torsional strength given in column 6. For some alloys, however, the agreement between the shearing strength and nominal torsional strength is close.

Column 14 of Table IV gives the ratio of rotating-cantilever endurance limit to tensile strength [bend-tension static endurance ratio, (7)]. This endurance ratio for the alloys of nickel and of copper varies greatly. The highest ratio, 0.49, is that for constantan; this ratio is about equal to the endurance ratio for an alloy steel. The lowest endurance ratio 0.215 is that for heat-treated Muntz metal, material BF-4.3.4.8. Between these extremes the other ratios are distributed.

Column 15 gives the ratios of alternating-torsion endurance limit to tensile strength. These ratios vary from 0.33 for nickel to 0.07 for heat-treated Muntz metal, material BF-4.8.

Influence of Chemical Compositions on Endurance Properties

The three variables that have the greatest influence on the

physical properties of these alloys are: chemical composition, plastic deformation and heat-treatment. In order to estimate and make allowances for the influences of plastic deformation it would be necessary to have a series of endurance test results for alloys in the fully annealed condition as well as in various stages of plastic deformation. To give this information for as large a series of alloys as this the total number of stress-cycle graphs would be great and the number of individual endurance tests would be enormous. For a few of the alloys of this series, however, endurance tests have been made of fully annealed material and endurance tests of material after various degrees of plastic deformation are under way. The graphs are not yet completed. Results of tension tests of some of these annealed alloys are given in Table II, so that comparison can be made with the properties of the material used for endurance tests. Moreover since many of the alloys in the series are "hot-rolled" their properties are not very different from those of annealed alloys. Although the influences of plastic deformation, therefore, cannot be entirely eliminated it is possible now to draw some conclusions about the influence of chemical composition.

The endurance ratio for nickel and these alloys of nickel with copper varies from about 0.3 to 0.4. This ratio apparently depends more on other influences than on the proportion of copper. Constantan, for example, shows a higher endurance ratio than pure nickel. Variations in the quantity and distribution of non-metallic inclusions are undoubtedly responsible for some of the differences between the endurance ratios of these nickel-copper alloys. One effect of non-metallic inclusions is shown in the stress-cycle graphs for monel metal. The wide variation in endurance properties between individual specimens shown in the graph of Fig. 3 is due to the large quantity of non-metallic inclusions in this alloy. Steel containing the large quantities of inclusions found in some of these non-ferrous alloys would not knowingly be utilized in machinery parts.

The influence of the proportion of tin on the endurance properties of copper-tin alloys cannot be definitely estimated at present since the "alpha" alloy used was cold-rolled. It seems probable, however, that the addition of tin to copper to form an

alpha alloy raises the endurance ratio, so that the endurance limit is raised more than in proportion to the tensile strength.

The influence of the proportion of aluminum on the endurance properties of copper-aluminum alloys can be roughly estimated by a comparison of the endurance limits of cold-rolled copper and the four aluminum bronzes as listed in column 9 of Table IV. It is believed that the degree of cold working received by the copper and the aluminum bronzes is about the same. With this assumption it appears probable that the endurance ratio as well as the tensile strength increases with increase in the proportion of aluminum. Aluminum bronzes Nos. 1 and 2 are "alpha" alloys, Nos. 3 and 4 have a duplex microstructure.

The influence of the proportion of zinc in copper-zinc alloys is roughly indicated by the results obtained with copper and copper-zinc alloys of four different compositions. It is worthy of note that alpha-brass nearly saturated with zinc, Muntz metal, Naval brass, and manganese bronze all have approximately equal endurance limits. As stated previously, heat treatment of the Muntz metal had little effect on the endurance limit. Since the alpha-brass was cold-drawn it should not be compared directly with the alloys of duplex microstructure in order to estimate the influence of zinc; it is probable that the endurance limit of annealed alpha-brass would be slightly lower. Nevertheless it seems evident that the addition of zinc to copper in excess of the proportion necessary to saturate the alpha solid solution does not greatly increase the endurance limit. The endurance ratios of the alloys of duplex microstructure are low.

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INTRINSIC VALUE OF HEAT SOURCES VERSUS THE FLUCTUATING ECONOMIC VALUE OF THE B. T. U.

By E. F. Collins

Abstract

This paper aims to point out that there is little of value in knowing the relative British thermal unit costs for a heat source unless all conditions surrounding the use of the heat source are also known. It is impossible to select that heat source giving the greatest "over-all" economy unless all conditions of its utilization enter in at their true intrinsic value for the specific process in hand.

We can only to a very limited extent at the present time standardize furnaces and fuels or heat sources, without grave danger of anchoring against further progress in the science of heat treating.

The metallurgist and "man at the fire" or operator must cooperate with the engineer and make intelligent use of the equipment furnished to give lowest over-all cost with the heat source selected, whatever it may be.

Not only the furnace but all auxiliary equipment for carrying out heat treating processes should be laid out to take advantage of any particular inherent advantages which may come to the thermal process due to the use of any particular heat source.

Some examples are given showing by areas of triangles, which represent heat energy value, how the intrinsic value of the British thermal unit fluctuates from one value to another due to different conditions of utilization, etc., and the conclusion is drawn that:

The highest "over-all" economy in heat treating processes frequently demands electric heat with its intrinsic characteristics, such as "form value," heat and temperature control, etc., rather than fuel heat with its lower Britsh thermal unit cost.

JUST as the chameleon changes his color to match that of the material or object on which he is located, so does the B. t. u. content of a heat source change its economic value, depending

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upon the heat treating process and the particular requirements of the work undergoing treatment. If this is so, then we cannot safely standardize sources of heat energy against heat treating processes without anchoring against further progress in the science of economical heat application. The factory manager or superintendent cannot follow the past practice, and keep a stock of standard furnaces from which, when a new process is put in operation, a furnace may be drawn, at random. When this is fitted with a burner that will give a sufficient temperature for the process, he cannot expect economical results, so long as he neglects problems of applying heat quantity as well as temperature. This plan is fast becoming obsolete and the shop executive department is largely organized, in well ordered shops, to follow such as the following plan.

Temperature-Time Cycles Must be Determined

The first step in the heat treatment of metals is that the metallurgist specify what heat energy must be imparted to each metal part and what definite temperature-time cycle must be followed. The temperature-time cycle is designed to secure certain desired characteristics in the metal after it has cooled, either in the air or by quenching in an oil or salt bath. Such cycles require that heat energy be imparted or abstracted at certain rates, giving due consideration to the metal shape, its exposed surface and underlying mass, its thermal conduction, chemical composition, and location of its critical points. The process of heat treating metals is fundamentally the problem of properly imparting or removing the correct amount of heat energy at a given time and rate, that the metal under treatment will yield the physical results required.

The heat treater or "man at the fire" must be skilled in the ways and means best suited for the transfer of heat as required by the specifications. It is important that his working tools or equipment shall be those best suited to his particular requirements. The source of heat energy, and means for its efficient conversion or generation, methods which allow economical conservation of generated heat, and the most satisfactory methods of transferring heat energy from one body to another should be incorporated in such manner as to give results desired for the particular processes.

Electrical Heat Versus Fuel Oil Heat

(On B. t. u. Generated Basis)

Just now it would be hard to find a problem of greater importance confronting the engineer than that of better and cheaper supply of heat. It is coming to be recognized by all classes of people that they must look to the heating engineer for the solution. Adequate and low cost heat is a public necessity for residents of this climate, and while the increase in domestic heating has grown, it has not been at all proportional to the increase of our population such as power has shown. A material increase of heat for industrial purposes, exclusive to that for power, has occurred, yet we find that the cost of heat has been advancing, whereas power has been made available at a slight rise in cost compared to the increased cost for fuel.

The cost for heat from primary fuels, such as coal, oil, and natural gas, has shown an increase compared to heat generated from electric power. Many remember when 6 to 8 per cent of the heat energy of the primary fuel burned under the boiler appeared at the electric bus as electric energy. Here electric heating had to be done with an over-all efficiency sufficient to wipe out at least a loss of 92 per cent of the heat units in the primary fuel, if its heat could be utilized in processes where 100 per cent heat generated existed.

Later 18 per cent of the heat of primary fuel was delivered as electricity, and we see our way to the realization of 28 to 30 per cent of the thermal content of primary fuel converted to electric power through the use of the mercury boiler. Assuming again that primary power may be used for heat direct at 100 per cent efficiency in heat generation, the electric heating will, on a B. t. u. basis, alone cost but four to five times that of the primary fuel, instead of the 16 to 20 to one ratio of two decades ago.

In the above it has been assumed that the primary fuel was utilized with an efficiency of heat generation of 100 per cent, i. e., the heat release from the primary fuel is considered to be the total of its thermal content. This is assumed only temporarily, to show clearly the advance made in converting heat into electric power.

Neglecting water power, heat is secured from primary source usually by combustion of fuel with air. This process cannot be

carried out practically with 100 per cent efficiency. As an illustration, 312,000,000 barrels or 13,104,000,000 gallons of fuel oil were used for fuel purposes in 1921 according to the Bureau of Mines, and while the exact extent of the loss in combustion is obviously difficult to determine, yet it is conservatively estimated by authorities that 25 per cent or 78,000,000 barrels was wasted through inefficient combustion.

The theoretical highest efficiency of conversion of fuel oil differs from 100 per cent efficiency by such losses as follows (average):

	B. t. u.	Per Cent
1. Moisture in fuel	18	.10
2. Burning of hydrogen	1295	7.00
3. Heat in dry flue gas	1295	7.00
4. Atomization of oil	185	1.00
5. Moisture in air	37	.20
6. Miscellaneous	1000	5.00
	3830	20.30

A thermal content of 18,500 B. t. u. per pound is here assumed and an air supply for practical combustion. One hundred per cent excess air is frequently met with and 10 to 20 per cent excess at best in metallurgical furnaces, occasion an additional loss. Hence it would seem that the estimated loss above given (25 per cent) is reasonably correct for practical purposes. These facts reduce the ratio of cost of heat from primary fuel, and that from electricity to average values of perhaps 3 to 3.75 to one in favor of the primary fuel; assuming that the heat developed from fuel oil and electricity may be utilized with the same efficiency and that fuel oil is the primary fuel used under the boiler for the electric generator. We are here neglecting purposely the labor and fixed charges. These will be considered later on.

We appreciate that the industrial heating problem is worthy of the mettle of the most resourceful engineer, whose recent work has caused us to realize that heat application in this country has too long been in the hands of the untrained draftsman rather than those of the competent engineer, who is familiar with the possibilities of all forms of fuel as well as electricity.

The furnace engineer recognizes and distinguishes between heat quantity and heat intensity, and visualizes the B. t. u. values separate and apart from heat control, heat potential or thermometer readings. He knows that heat, light and electricity are all basically electric phenomena and follow the same general laws.

Hence the laws for the flow of electricity in a circuit, with proper modifications, apply to the flow of heat through thermal conductors and resistors. For example, Ohm's law for electric flow.

C equals $\frac{E}{R}$ is also true for constant currents of heat, where E is the heat potential impressed on the thermal resistor, or difference in temperature at terminals of circuit, and R is the thermal resistance of circuit in thermal ohms. C, the heat flow, is then obtained in watts or B. t. u., depending upon the system of units used. And so we may use the electric law, with proper substitutions of thermal units for the electric, and get laws for heat application and methods for attacking heating problems in a practical way.

It was in 1799 that Count Rumford anticipated the mechanical theory of heat, and Sir Humphrey Davey demonstrated it by melting two pieces of ice by the friction of one upon the other. It was fifty years later, in 1849, that Joule announced that he had discovered a measure of heat quantity,—a numerical and definite ratio of heat to work. In 1878 an exact measure value of heat energy was given, namely, the British Thermal Unit (B. t. u.), defined as the heat energy equivalent to 772.4 foot-pounds of mechanical work. Hence we have had forty-six years to formulate and use "heat energy" engineering laws, and therefore in the main many "rule of thumb" methods have been formulated from such information as was used by a body of "practical men" who had learned the laws of temperature before they knew what heat quantity was or how to control its distribution economically to meet any heating cycle specified. Our engineers know that the B. t. u. has a floating value, and in consequence that no one heat energy source is superior for economical heat results at all times and in all places. Knowing the requirements for heat energy application they select the heat energy source best suited to the individual case, and this selection does not by any means follow that source, having the greatest thermal content and cheapest B. t. u. In other words, the B. t. u. content or even the cost of B. t. u. generated dictates only in part the proper heat energy source.

Stating this differently, let the thermal unit be conceived to

Relative Cost Values of Primary and Secondary Fuels and Over-All Values in Heat Treating Furnaces. Bituminous Coal=$5.00 Per Ton, Fuel Oil=10c Per Gal., Electricity=1c Per K. W. H., City Gas=$1.00 Per 1000 Cu. Ft.=Values of Commercial Costs Assumed. Compiled and Calculated for Temperatures of 1600° F. Primary and Secondary Fuels—(5) Heat Utilized for Equal *Fuel* Costs.

be represented by the area of an equilateral triangle (Plate I); its intrinsic value is dependent upon those conditions surrounding it. In truth the "over-all" intrinsic value of any thermal unit for a process, is a composite which takes true account of the complete value, when analyzed from all angles, or requirements, of a specific thermal process.

The principal area values of the heat energy may be conceived to be as follows:

Area (1) Energy value stored in fuel, yet in the earth.
Area (2) Commercial value at burner.

(a) Based on B. t. u. content.
(b) Based on B. t. u. heat units generated.
(c) Based on B. t. u. heat units available for work.
(d) Based on B. t. u. heat units utilized by work.

Area (3) Engineering value.

(a) Utilization of heat values (See Fig. 17).
(b) Heat generated value.
(c) Heat application and control value.
(d) Heat conservative value.
(e) Heat temperature control value.
(f) Miscellaneous values.

Area (4) Form value.

(a) Saving of labor (See Ex. D).
(b) Saving in storage, floor space.
(c) Miscellaneous savings.

"Form value" may be defined as an advantage resulting from physical condition or chemical combinations in a heat energy source; entirely separate, and apart, from B. t. u. content, such that an advantage comes about in the application of its heat to useful service. The price of fuel- or electricity-type furnaces, and the heat balance for the process, are excluded from this conception of "form value."

Area (5) This area covers the following:

Specific intrinsic value for the process in hand, due to unusual or local conditions or exacting requirements; advantages in operation involving the personal element of operators; labor of handling product for heat treating, designs giving unusual quality, production, efficiency, costs, etc.

Area (6)

"Over-all" costs. This area is a composite and made up from areas (1, 2, 3, 4 and 5) and is the true economic value of the heat energy source corresponding for a given heat energy application. This is the floating value of the B. t. u. for this specific process.

Referring to Plate I, let us note the real and phantom values which the B. t. u. assumes under the conditions outlined above. It is desired to consider values as met in working temperatures of 1600 degrees Fahr. and for the primary fuels, (1) bituminous coal, (2) fuel oil; and for the secondary heat energy sources, namely, (3) city gas, and (4) electric heat. Fig. 1 and Fig. 2 are equal triangles representing 1 B. t. u. of coal and 1 B. t. u. in fuel oil. Here we have the case of heat source storage in the earth, and they have energy value alone and no commerical value until taken from the earth, so far as man's use of them is concerned. They are then in all respects equal in value.

Commercial Cost or Value

Commercial value comes to the B. t. u. due to its being taken from the earth and being transported and distributed to the burner for combustion; and from the demand for its use in the generation of heat.

In this discussion we have assumed this commercial cost to be $5.00 per ton for coal running 12,500 B. t. u. per pound and 10 cents per gallon for fuel oil running 140,000 B. t. u. per gallon. With these general figures, as base, any other local value may be readily substituted for specific conditions. Fig. 3 shows that we have selected 1 B. t. u. in coal, and Fig. 4 shows that for the same cost we can get only 0.23 B. t. u. in fuel oil. Here commercial

cost has changed the 1:1 ratio for coal and oil (Figs. 1 and 2) to better than a 4.3 to 1 ratio in favor of coal; and the solid sided triangular areas (Figs. 3 and 4) show the values of coal and oil respectively. We now proceed to convert the stored energy of the coal and the oil into heat by combustion with air. Figs. 5 and 6 show their values when converted into heat available for application to any given thermal process. These relative values have changed from the 4.3 to 1 to a 4 to 1 still in favor of coal.

Generation of Secondary Fuels

If we now take the available heat in Figs. 5 and 6 and generate electricity from Fig. 5 and gas from Figs. 5 and 6, we get the areas 0.18 B. t. u. of electricity from 1 B. t. u. of coal with the steam turbines and hope that we may soon realize 0.28 to 0.30 B. t. u. per B. t. u. of coal, with the mercury boiler. Overhead costs for

SOURCE OF HEAT	PER CENT OF AIR FOR PERFECT COMBUSTION	CALORIFIC VALUE OF FUEL	TEMP. OF FURNACE	RATE PAID FOR FUEL OR POWER	COST PER 100,000 B.T.U.	LOSSES PER CENT OF AVAILABLE B.T.U. LOST IN FLUE GASES	LOSSES ASSUMED RADIATION B.T.U.	TOTAL B.T.U. REQUIRED FOR 100,000 B.T.U. EFFECTIVE	THERMAL EFFICIENCY OF FURNACE	COST PER 100,000 B.T.U. EFFECTIVE
ELECTRICITY		3412 PER K.W.H.	400°F	1¢ PER K.W.H.	$.293	0	15000	115000	87.0	$.337
"		"	1600°F	"	"	"	20000	120000	83.5	$.352
"		"	2300°F	"	"	"	30000	130000	77.0	$.380
"		"	2800°F	"	"	"	40000	140000	71.5	$.410
CITY GAS	100	450 PER CU.FT.	400°F	$1.00 PER M	$.17	15.0	15000	135000	74	$.230
"	150	"	"	"	"	17.5	15000	139000	72	$.236
"	100	"	1600°F	"	"	44.0	20000	214000	46.7	$.364
"	150	"	"	"	"	51.0	20000	245000	40.8	$.416
"	100	"	2300°F	"	"	60	30000	325000	30.8	$.552
"	150	"	"	"	"	70	30000	433000	23.1	$.736
"	100	"	2800°F	"	"	72.5	40000	509000	19.7	$.865
"	150	"	"	"	"	85	40000	933000	10.7	$1.585
FUEL OIL	100	19,000 PER LB.	400°F	10¢ PER GAL.	$.0748	14	15000	134000	74.6	$.100
"	150	"	"	"	"	17.5	15000	139000	72.0	$.104
"	100	"	1600°F	"	"	40	20000	200000	50.0	$.150
"	150	"	"	"	"	55	20000	267000	37.5	$.200
"	100	"	2300°F	"	"	56	30000	296000	33.8	$.222
"	150	"	"	"	"	77.5	30000	577000	17.3	$.432
"	100	"	2800°F	"	"	67.5	40000	430000	23.3	$.322
"	150	"	"	"	"	94	40000	2,330,000	4.3	$1.745
BITUMINOUS COAL	100	13,850 PER LB.	400°F	$5.00 PER T.	$.0020	11	15000	129000	77.5	$.0258
"	150	"	"	"	"	15	15000	135000	74.0	$.0270
"	100	"	1600°F	"	"	38.5	20000	195000	51.3	$.0390
"	150	"	"	"	"	52.5	20000	253000	39.5	$.0506
"	100	"	2300°F	"	"	55	30000	283000	34.6	$.0570
"	150	"	"	"	"	75	30000	520000	19.2	$.1040
"	100	"	2800°F	"	"	65	40000	400000	25.0	$.0800
"	150	"	"	"	"	90	40000	1400,000	7.15	$.2800

Table I. Data Showing the Relative Thermal Efficiency and Cost of Electricity and Various Fuels.

generation compel us to pay, it is assumed, 1 cent per kilowatt hour. This cost reduces the B. t. u. value from 0.18 to 0.07 B. t. u. (Fig. 7) for electricity, equal to the cost of 1 B. t. u. for coal. From heat available, Figs. 4 and 5, equivalent to 0.08

B. t. u. city gas is generated at $1.00 per thousand cubic feet, which cost reduces to a value of 0.12 B. t. u. for city gas (Fig. 8).

Utilization of Heat in Heat Treating

In Figs. 9 to 12 inclusive is shown how the effect of efficiency of utilization affects the true value of the B. t. u. This efficiency of utilization may be taken as that given in Fig. 17 at 1600 degrees Fahr. Then coal, Fig. 9, has a value of 0.28 B. t. u., while the other primary fuel (oil) has taken on the value of 0.12 B. t. u. The secondary heat sources have taken on values of 0.05 B. t. u. for city gas and 0.06 B. t. u. for electricity (Table I).

With the conditions assumed then, the utilization, i. e., the B. t. u. actually put into the work for a given cost will be in the following ratio: Coal, 1.0, fuel oil, 0.43, city gas, 0.18, electricity, 0.22. The foregoing is on a B. t. u. basis only, wherein the B. t. u. value was determined by factors of commercial cost, efficiency of combustion of fuels, and efficiency of application.

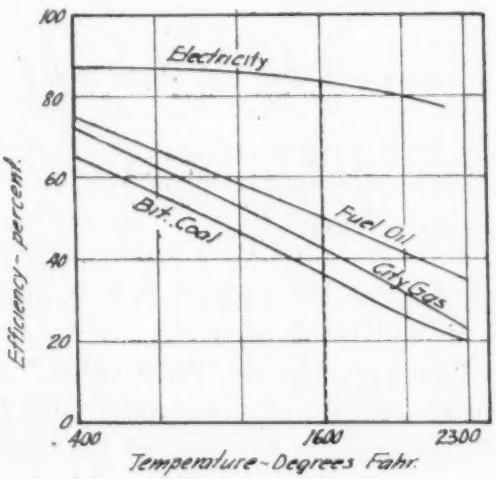


Fig. 17—Efficiency of Utilization of the B. T. U. Electric and Fuel Fired Furnaces. Calculated for Average Conditions Required for Steel Treating.

Other Factors Influencing Over-All Costs

We will now consider a few examples wherein "over-all" costs are influenced to a greater or less extent by other factors than B. t. u. utilization costs. These examples should be sufficient to convince all that it is frequently possible for the relative B. t. u.

cost to sink out of significance when the "over-all" cost is made up, and it must not be relied upon singly to give any indication as to the heat source to be used for highest economy.

Example A. Suppose that certain machine parts whose value is P be heat treated in a poorly designed oil-heated furnace for a cost of

$\left(\frac{P}{100}\right)$, which is 1% of the value of the parts

and upon test 10 per cent or $\frac{P}{10}$ defective parts result.

Again, the same number are treated in the electric furnace for cost

$\left(\frac{P}{50}\right)$, which is twice as much as the other,

with no defects. Which type of furnace is the most economical, other conditions being equal? Answer: Oil furnace cost to get 100 per cent perfect parts was

$$\frac{\left(\frac{P}{100}\right)+\left(\frac{P}{10}\right)}{.90}=\frac{11\,P}{90}$$

and the electric furnace cost for 100 parts was $\left(\frac{P}{50}\right)$

$$\frac{\left(\frac{P}{50}\right)}{\left(\frac{11\,P}{90}\right)}=\left(\frac{9}{55}\right)$$

in favor of electric heat or the electric B. t. u. may cost about six times the oil B. t. u. and break even.

Example B. Suppose, due to "form value," saving in labor, floor space, improved quality, etc., amounts, with the electric furnace above, to 10 per cent on the cost of the untreated parts, P over the oil furnace performance. It is evident that this saving must be credited to Fig. 6 to get Fig. 7 showing the "over-all" cost.

Thus,

$$\left(\frac{P}{50}\right)-\left(\frac{P}{10}\right)=$$

"over-all' cost of electric furnace treatment, or minus

$$\left(\frac{4\,P}{50}\right),$$

which means that the correctly designed electric furnace is earning money over the poorly designed oil furnace (Figs. 13 and 14). Here we see that the ratio to break even on "over-all" costs is

$$\frac{\frac{11\,P}{90}+\frac{P}{10}}{\frac{P}{50}}=\frac{\frac{20\,P}{90}}{\frac{P}{50}}=11.1$$

Example C. Suppose a carburizing furnace, oil-heated, cost for fuel 2.3 times the coal furnace for the work P, and the cost was

$$\left(\frac{P}{200}\right), \text{ for coal heated}$$

and suppose that rejects in oil furnace were 10 per cent and in the coal-fired furnace 20 per cent. Which is the most economical furnace for the work, all other conditions being equal?

Answer: Cost of work done in oil furnace—

$$\left(\frac{2.3\,P}{200}\right)+\left(\frac{P}{10}\right)=\left(\frac{22.3\,P}{200}\right)$$

and cost in the coal-fired furnace =

$$\left(\frac{P}{200}\right)+\left(\frac{2.\,P}{10}\right)=\left(\frac{22.\,P}{200}\right) \text{ or } \left(\frac{.3\,P}{200}\right) \text{ in favor of coal.}$$

Example D. Suppose the labor of coal and ash handling, floor space, attendance, and form factor, make oil heat show 10 per cent of value of untreated product saved over the coal furnace. Then we will credit the oil furnace diagram with this and get an "over-all" cost in terms of B. t. u.

"Over-all" cost of oil furnace

$$=\left(\frac{22.3\,P}{200}\right)$$

and the same for the coal-fired furnace is

$$\left(\frac{22.\,P}{200}\right)+\left(\frac{P}{10}\right)=\left(\frac{42\,P}{200}\right),$$

or a difference of

$$\left(\frac{42\,P}{200}\right)-\left(\frac{22.3\,P}{200}\right)=\left(\frac{19.7\,P}{200}\right)=\frac{9.85\,P}{100}$$

or ratio of oil to coal cost "over-all"

$$=\left(\frac{42}{22.3}\right)=0.53$$

in favor of oil. (Figs. 15 and 16.)

The foregoing has been more or less a discussion of possibilities, in general, which may actually be met in comparing one source of heat against the other. In order to show that such possibilities do become actualities in working installations, we are giving details of a few representative installations where the electric B. t. u. has such inherent advantages for the heat treating process in hand that its commercial cost is an insignificant component of the final and total "over-all" cost.

Calorific Values of Heat Sources and Over-All Costs

There is no direct constant relation between the calorific value of heat source and the "over-all" cost in industrial heating. The "over-all" cost is a function of (1) the character of the "heating cycle" required by the product under manufacture; (2) the equipment provided for the application of heat; (3) the conditions under which the equipment is operated; (4) the efficiency of operators; and (5) the cost of the heating medium, be it electricity or fuel. All these factors combined determine the factory costs whether fuel or electricity is used. The quantity consumed affects the cost of production usually, to a lesser degree than any other single factor listed above. Fuel consumption, for a given process, may easily be twice as great in one furnace as in another doing the same work, but having a more efficient design. Again, it is true that a well designed equipment may be so inefficiently operated (especially in fuel furnaces) that it consumes double or treble the quantity of heating fuels or electricity that a watchful and highly efficient operator would use for the same production with correct methods of operation.

And since, when all has been said and done, the human element may very materially modify results, attempts should, therefore, be made to take, so far as practical, every opportunity offered to minimize the effect of human manipulation. I refer to such things as perfect conversion of heat met with in the electric furnace and the automatic control of power or temperature which is almost perfectly accomplished in the present day electric furnace.

Auxiliary Equipment

Hand in hand with the proper selection of furnace for indus-

trial heating processes and coincident with the selection of electric heat energy, there should be well worked out specifications covering the best type, its design, size of unit, number of furnaces, their arrangement in the line of production and the grouping of auxiliary equipment, such as transportation, handling, cooling and testing.

The same definite natural laws control cooling as well as heating. Hence for successful results and low "over-all" costs, it is important that the cooling equipment be given the same careful design as the heating equipment. Control must be provided, so far as is possible, to maintain required relations between temperature, cycles of heating and cooling, giving due consideration to surface exposed and underlying mass in order to get maximum quality and quantity of production and economical operation.

Wrong Deductions in Comparing Heat Source Efficiencies

Many wrong deductions regarding the efficiency of electric heating come from comparing an inefficient electric furnace, perhaps improperly operated, and in design not suited to the specific process and manufacturing conditions, with a fuel-fired furnace which is suited to the fuel, the process, and which is more efficiently operated. The difference in economy resulting is too often charged to the difference between electric heating and fuel heating. In this connection, the writer recalls an example of such erroneous deductions. A piece of heating equipment improperly designed for the application of electric heat with economy, was nevertheless fitted with electric heaters. It turned out a product with a consumption of about one kilowatt hour for 4.5 pounds, 500 degrees Fahr., when electrically heated. This piece of apparatus was almost ideally suited for fuel heating, however, when operated with oil heating gave a cost for treating the product of only one-ninth of the cost with eletricity.

Proper design and operation of apparatus suited to the same work, when electrically heated, would have given 35 pounds per kilowatt hour (or about eight times 4.5). The reason for doing work at one-ninth the cost in the fuel-fired equipment was due to the use of a design suited to oil heating and unsuited to electric. It would not have been reported that electric heat was

nine times more expensive than oil for the same purpose, had those making the comparison not have been mistaken as to the source of difference. They erroneously charged it to the use of different "fuels" rather than to designs which defeated the proper application of electric heat.

In order to forestall charges of misapplication of a "fuel," designs must take advantage of the inherent characteristics of electricity or a fuel, as the case may be. Again, furnaces of the box type, used by intermittent charging, should not be compared to "tunnel" continuous conveyor type, neither should "non-compensated" or "non-regenerative" furnaces be compared to compensated or regenerative or reflexed heat types and expect equal performance. In such cases, we should look for a more or less wide variation in performance between the different types when used under the same conditions. The lowest "over-all" cost of production will usually demand one particular type, depending upon requirements of the product.

Inherent Advantages of Heat Sources

The effect of inherent advantages on "over-all" cost with any fuel or heat source (fuels or electricity) may be very much veiled in practice by a wide divergence in the attention given such economic advantages, depending upon the managerial ability of the users. Under a poor management, the lack of appreciation of inherent advantages of a fuel may render its use wasteful. Electric energy, however, under good management renders substantial returns by virtue of its inherent advantages in many industrial processes.

As an exhibit demonstrating the inherent suitability of electric heat for almost entirely eliminating the decarburization and scaling of 1.10 per cent carbon steel during heat treatment, an instructive record of carefully observed results, are shown in Figs. 18 to 23.

The parts on which these observations were made were of 1.10 per cent carbon steel round, ¾ inch diameter and 2 inches long.

The furnaces used were (1) a surface combustion gas furnace

fired with city gas, and (2) an electric metallic resistor furnace of the direct heat type.

The temperature to which steel was heated ranged from about 1400 degrees Fahr. to about 1550 degrees Fahr., and work was quenched following its heating, to harden.

Scale in Electric Versus Gas

Let us first look at Fig. 19, where diameters after hardening are shown for different temperatures and for different spaces of

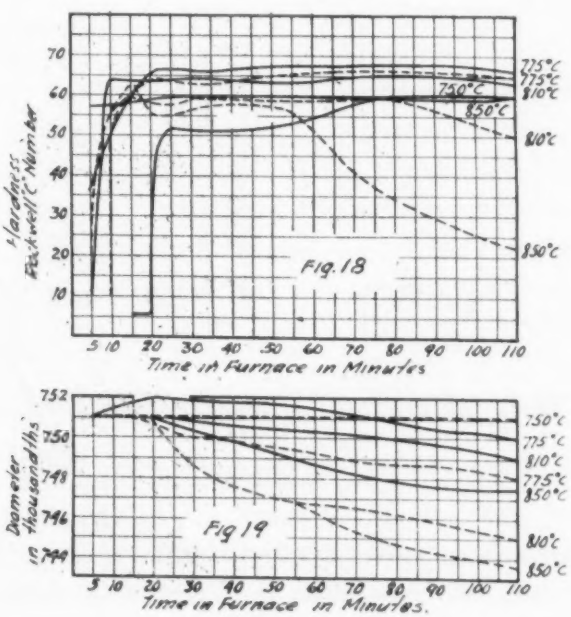


Fig. 18 and 19. Tests for Decarburization on 1.10 per cent Carbon Steel.
Solid line—Electric Furnace—Dash line—Gas Furnace.

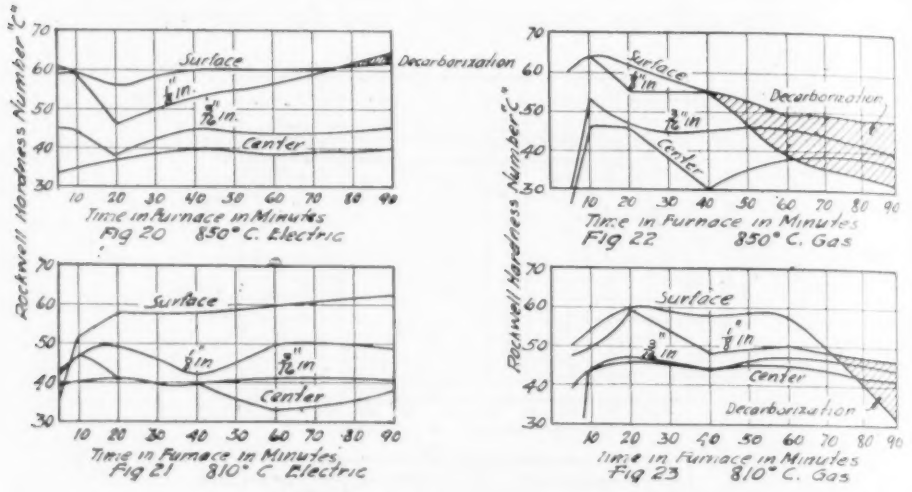
time beginning with five minutes in the furnace. Observations were made for a heating period increasing by 5 minutes up to 110 minutes.

The original dimensions of round 1.10 per cent carbon steel stock was 0.751 inch in diameter, by 2 inches long before heating. The decreased diameter after quenching is assumed to indicate the amount of scale formed and which is snapped off in the quench. Note that this decrease in diameter is about equal at about 1430 degrees Fahr. in the gas furnace, and at 1560 degrees Fahr. in the

electric furnace, with equal time of heating, while almost twice as much scale is formed in gas furnace at 1560 degrees Fahr. as in the electric under the same conditions.

Hardness in Electric Versus Gas

The hardness rises to a maximum for work done in the electric furnace when a temperature of 1425 degrees Fahr. is used, and a slight falling off occurs at increased temperatures, due perhaps



Figs. 20 to 23. Tests for Surface and Under Surface Decarburization with 1.10 per cent Carbon Steel.

to the increased solution of "hard carbide" and to the formation of greater amounts of "austenite." There is no decrease of hardness for long periods of heating, which means that the decarburization is almost negligible. To be sure, we note that hardness occurs in a shorter period with higher temperature, but this is not the maximum hardness obtainable. We see that twenty minutes is required for maximum hardness for 1430 degrees Fahr., whereas for lower temperatures the work was heated for a longer period. The reason that the gas-heated stock does not reach an equally high degree of hardness may be due to the effect of some surface decarburization.

In no case could there be detected with the microscope any measurable area of totally decarburized surface metal, except those heated to 1560 degrees Fahr. in the gas furnace for the longer periods. Hence to get an exact comparison on the cross section.

Rockwell hardness numbers were determined (1) at the surface, (2) at depths of 1/8 inch and 3/16 inch below the surface, and (3) at the center.

In the electric furnace the maximum hardness is practically constant, even through the long periods of heating. The adjacent underlying zone is always shown to be less hard. At 1560 degrees Fahr. an exception is noted in that the interior metal increases in hardness and ultimately exceeds the surface hardness. This may be explained as a result of surface decarburization shown as shaded area on Figs. 22 and 23.

In the gas furnace the surface decreases in hardness as does the underlying stock at 1480 degrees Fahr., but at a greater rate. In much greater quantity we find decarburization over that in the electric furnace, yet at lower temperatures. The decrease in diameter corresponds to the area on the curve and under the horizontal. In the gas furnace the decrease of diameter and increase of decarburization have reached surprisingly high values at a temperature of 1560 degrees Fahr.

The author feels that no comment is necessary to lead one to decide from the above, the relative merits of each furnace for metallurgical work.

Electric Furnace and Conservation of Energy

Coal, oil and gas, and water power are the principal present day sources of energy in the country. This group furnishes stored energy required by our modern conditions. It is estimated that about one-third of this energy is devoted to the production of heat and light, and something like 150,000,000 tons of coal is used for metallurgical processes. Fuel is used with an average efficiency the country over of about 10 per cent in metallurgical furnaces. An average of 250 miscellaneous oil-burning furnaces gave a thermal efficiency of 9.2 per cent.

It is interesting to compare the above 9.2 to 10 per cent, and that of the electric furnace fed from a good steam-electric plant which delivers 12 per cent of the fuel at the bus, or of a super-steam electric plant which delivers 19 per cent of the fuel B. t. u. at the bus, or the mercury boiler plant which promises 30 per cent at the bus. The heat treating furnace with a thermal efficiency of 80 per cent will in the first case utilize 9.6 per cent of the fuel

in useful work, while in the second case, it will deliver 15.2 per cent and in the third and last case, at the same efficiency, it will deliver to the charge to be heated 24 per cent of the energy of the coal burned under the boiler, and it becomes evident that electric heat stands ready to conserve coal and oil supply.

Conclusion

In conclusion, it is hoped that the foregoing discussion has clearly established some facts and with them the two general observations to follow. If it has accomplished this much, the main object of this paper will have been achieved.

These observations are:—

First: The B. t. u. has a fluctuating value and its value becomes fixed only for fixed conditions surrounding its utilization for each heat source.

Second: The highest "over-all" economy in heat treating processes frequently demands electric heat with its intrinsic characteristics, such as "form value," heat and temperature control, etc., rather than fuel heat with its low B. t. u. cost.

Finally while the electric heat treating furnace cannot be offered under all conditions and in all places, it has, however, made very satisfactory progress toward large economic savings, and its ability to conserve we are sure will rapidly and vastly increase as we move forward in the near future, toward the mercury boiler, super-power plan, and the developments possible in our great and small waterfalls.

Discussion of this paper begins on Page 123.

SELECTION OF FUELS FOR THE HEAT TREATMENT OF METAL

By J. A. Doyle

Abstract

In the selection of fuel, the first considerations should be the quality and cost of the finished product and the comfort of the operatives. These results are determined by a suitable combination of the fuel, the equipment, and the operating methods. Comparisons between fuels, as such, are misleading without consideration of the furnace and the method of operation, because the cost of fuel is determined by the quantity consumed and not by the price alone. Each form of fuel or electricity and furnace has its field of usefulness as well as its limitations. All comparisons of fuels should be based on consideration of the results desired under specific conditions and with equipment properly adapted to each.

SELECTION of a suitable fuel, or electricity, for heat-treatment processes should be made with appreciation of the fact that the value of the result sought is to be measured by the quality and overall cost of the finished product; not merely by the price or consumption of fuel or electricity, temperature record, heat balance, or some such incidental phase of the heat-treatment process as a whole. The real problem, from the heat treater's point of view, is that of producing a quality product at low cost, and the use of such form of fuel, or electricity, and such character of equipment for heating, cooling and handling, as will produce this result under his specific manufacturing conditions.

Any method of selection, based on abstract comparison of different forms of fuel, or electricity, and the claimed advantages of one over the other is inaccurate, misleading and out of date in fact, though apparently not in effect. Each form has its field of usefulness, as well as its limitations, all of which vary with the nature of the heating process, the type of furnace or other heating appliance, the method of operation, the manufacturing require-

A paper presented at the Sixth Annual Convention of the Society held in Boston, September, 1924. The author, J. A. Doyle, is vice-president of the W. S. Rockwell Co., New York.

ments, the plant conditions, and many other factors, as outlined in the accompanying chart, any one of which may influence the choice under specific conditions.

Much of the prevailing conflict of ideas on the subject is due either to a misunderstanding of the relation of the so-called "fuel problem," to the real problem that confronts the heat-treating department—(i. e.—the quality and overall cost of the finished product); or to commercial propaganda calculated to further the use of some particular form of fuel or electricity, or some special form of apparatus or material to which that specific form of heat energy may be adapted.

The situation is confusing to one concerned with the selection of industrial heating equipment properly adapted to his specific requirements. He is confronted with conflicting claims of enthusiastic advocates of many different forms of fuel, electricity, furnace material or heating apparatus; and with evidence or opinion in tales of success or failure that may be far removed from proof or fact. He longs for recourse to a recognized Court of Appeals for an unbiased opinion of the relative merits of the many different forms of solid, powdered, liquid or gaseous fuels; of the arc, resistance or induction methods of heating electrically; and of the unending variety of different types of furnaces or other heating appliances adapted to these various heating media.

In considering solid fuels, he learns something of the claimed relation of hand-firing to stoker-firing of different forms of bituminous or anthracite coal, and of powdered coal.

Consideration of fuel oil raises a question as to the suitability of heavy oil or light oil. A choice is made difficult by conflicting claims for dozens of different types of so-called "oil burners" designed for steam, high or low pressure air (or both), and of an equally great variety designed to atomize mechanically.

He is informed that gas is the best fuel and wonders if it should be city gas, natural gas, water gas, oil gas, mixed gas, hot or cold producer gas, or some other form of gas.

A desire to avoid the difficulties with fuel, leads to the thought of electricity, and of the possibilities with either the arc, induction, or resistance methods; of resistors in different forms of refractory or metallic material; of round wires, or flat wires, that may be exposed or muffled; of cast or rolled metallic units; of

high and low frequency; of the possibilities of automatic temperature control with fuel or electricity, and so on, ad inf.

When proper study of the problem as a whole discloses the fact that the economic relation of the many different forms of fuel or electricity continually varies with an unending and ever-changing variety of furnace and appliance design, he may conclude that when no one knows, every one has a right to guess. So, he makes his guess, assuming that they are all cheap at any price; that each is better or a great deal worse than the other, and that each has its earnest advocates of the type that made Alabama famous.

This statement of an undesirable condition is not overdrawn, as it illustrates part of a time-wasting process of more or less useless discussion that is of daily occurrence. It is imperative that a more common sense perspective of the problem should be cultivated to encourage proper development of the many industrial arts in which heat plays a prominent part; to effectively contribute to the conservation of energy resources; to provide better working conditions for operatives in the shops; and to encourage more constructive thought of the real question at issue, i. e., the quality and overall cost of the ultimate product or service.

A good move, in the direction of improvement, would be to cultivate the thought that many of the prevailing ideas, and much of the discussion, is really beside the point at issue; that no one form of fuel, food, or medicine, is suitable for the general run of requirements; that an attempt to urge the use of any one form of furnace or heating appliance is the equivalent of an attempt to devise one form of dwelling to meet the country wide requirements of housing, or to provide one form of fuel or equipment for all of the domestic heating operations in that dwelling; that we are more concerned with the practical problem of heat-treatment, than with the theoretical condition established by the usual discussions of the so-called "fuel problem," most of which are as interesting and constructive as a debate on the relative merits of wine or water as a beverage, without sufficient thought of the purpose, or occasion, for which the respective fluids may be properly considered.

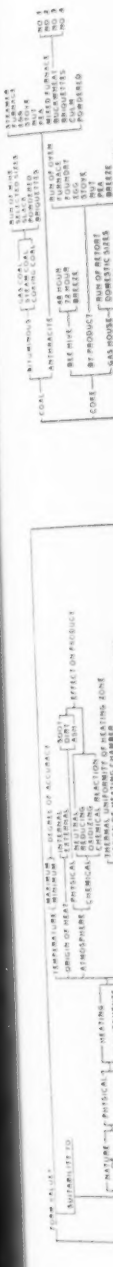
The technical coloring that has been acquired through years of thought along such lines, lends an air of mystery and complication in the matter of solution, but this is more formidable in

appearance than in fact. It is the natural result of a condition whereby the tail of fuel discussion wags the cat of heat-treatment practice. We can well do with less useless discussion about fuels, and more constructive thought of the underlying principles affecting the heating, cooling and handling of products to be heat-treated, and comfort of the operatives, along the common sense lines followed in the kitchen. There, quality goods are generally delivered in spite of ignorance of the technique of fuel values and the like, which have too long distracted the attention of heat-treaters from the real point at issue.

A perspective of the problem from this angle will pave the way for constructive thought in the matter of selection of fuel, or electricity, and equipment for the shop along the lines that are usually followed in the household, and without the unending and more or less misleading discussion of fuels that effectively retards better methods of heating, cooling and handling material, and better working conditions for the operatives, that form the basis of a constructive effort to produce better and cheaper heat-treated products.

It is in order for this Society to encourage such view in the interests of the art and all those concerned with the practice of it. Certainly, it suggests the possibility of steering a straight course out of the woods of doubt represented by the mental tanglefoot of conflicting technical opinion, or competitive commercial interest. The journals devoted to fuel oil, city gas, natural gas, coal, electricity, and other forms of heat energy, or equipment or material adapted to them, continually carry matter calculated to convey the impression that the particular form of heat energy to which the publication is devoted is better than any other; and evidence in the form of tests or replacements of one by the other is offered to support such contention. This, on the very face of things, is a ridiculous and illogical condition. It, naturally, develops different schools of thought which, from the standpoint of logic, are on a par with the conflicting political, legal or religious views that mix up things in general.

Improvement is not likely to be effected until it is appreciated that whatever is best for the art as a whole should be good enough for every one connected with it; that those concerned with the selection of fuel, or electricity, and heat-treating equip-



FACTORS GOVERNING SELECTION OF FUEL (HEAT ENERGY)
FOR
INDUSTRIAL HEATING OPERATIONS

ment, should realize that there is a big country outside the property lines of their respective plants in which a great deal of development may have been effected, of which they may have little or no knowledge; that those concerned with the development of different forms of heat energy or equipment should realize that each has its field of usefulness, as well as limitations; that the proper economic relation between any two (at a given time and place) can be most effectively determined by comparison of the nature of the equipment considered with each, and the suitability or "form value" of the combination as a whole to the requirements of the case in hand, along the lines usually followed under similar conditions in the fields of power, transportation and illumination.

Discussion of this paper begins on Page 123.

GAS AS A FACTOR IN IMPROVING QUALITY STANDARDS AND LOWERING PRODUCTION COSTS OF HEAT TREATED STEEL

By H. O. Loebell

Abstract

The author of this paper has discussed the importance of gaseous fuels in their application to the heating and heat treating of steel. He has compared gaseous fuels with liquid and solid fuels and electricity as a means for heating steel and has drawn conclusions which favor gaseous fuels in preference to all other types. He points out that the use of gas as a fuel is the most nearly perfect form of fuel that there is, due to the fact that it is already in the state whereby it can be readily mixed with air and be burned, whereas with the solid and liquid fuels, it is necessary to convert them to the gaseous state before they are suitable for burning. He further points out that electricity as a means for heating is an uneconomical and costly method due to the power losses in converting coal to heat energy and heat energy to mechanical energy, mechanical energy to electricity and then the conversion of electrical energy to heat. He states that the greatest thermal efficiency which can be obtained in the development of electrical energy is an over-all thermal efficiency of 18 per cent. Various types of furnaces, recuperators, etc., are described.

THERE is, perhaps, no phase of industrial activity in which the problem of fuel is of greater importance than in those industries which are engaged in the production and manufacture of steel and ferrous products. We find considerable difference of opinion as to which of our present fuels is most desirable for operations involving the heat treatment of steel and allied heating processes. Some manufacturers find electricity more desirable, while others continue to use solid fuels, liquid fuels, and in many cases gaseous fuels.

A paper presented before the Boston Convention of the Society, September, 1924. The author, H. O. Loebell, is vice-president and general manager of the Combustion Utilities Corporation and president of the Surface Combustion Co., New York City.

As an engineer connected for many years with the industrial application of central station gas the author feels that after a careful analysis of the values of our different fuels from the standpoints of permanency of supply, efficiency and effectiveness of utilization, economy in production, and the betterment of quality standards, that the most desirable and ultimate fuel for the steel treating industries is gas.

During the past ten years the sale of gas for industrial purposes by the gas companies of the United States has increased more than 1000 per cent. Besides, this tremendous growth has taken place in spite of the fact that, generally speaking, the price of gas has been between three and five times greater than that of the competitive liquid and solid fuels. There can be only one explanation for this extraordinary expansion—a more widespread appreciation of gas as the ideal and ultimate fuel.

If this is the case, if gas is really the fuel which will ultimately take care of all industrial heating operations, there naturally must be some fundamental and basic reasons why this is so. This paper was written with the thought of analyzing the basic considerations involved, in order that we may all arrive at some definite conclusions as to what developments we may expect in giving the industrial world a better industrial fuel.

As the author sees the problem, there are two basic considerations involved,—first, the scientific factor which involves the effective utilization of the fuel, and secondly, the economic factor which involves not only the present cost of the fuel, but also the supply of crude materials available for its manufacture and general trend of its availability at the lowest possible cost to the industrial plant.

Control—The Important Factor

The outstanding success of the use of central station gas as an industrial fuel has been due to the fact that gas as a fuel is scientifically correct. Gas as an industrial fuel allows for complete control of both the physical and chemical characteristics of each and every heating operation. In bringing out this thought let us analyze the methods which we utilize for the progressive development of our industrial processes.

We are living in an age when the character of our industrial heating processes is fast emerging from the category of an art to

that of a science. The average heating process is no longer dependent upon the traditions of the past and the intuition and general skill of the workman. The great progress that has been made and is being made is due to scientific control—the development in the research laboratory of scientific methods which definitely prescribe the physical and chemical conditions under which can be obtained the highest quality standards of production at the lowest possible cost.

It is largely true that our great improvements are developed in the research laboratories. Is it not the developments in the laboratory of the average industrial company that attain the zenith of perfection in regard to each and every process? To-day the progressive industrial organization has a research laboratory which makes a very careful study of its various heat processes and prescribes those conditions under which different materials can be heat treated to obtain the highest quality standards of production with the minimum spoilage and with the maximum economics involved.

With these results in hand, it would seem an easy matter to apply these data to the commercial operations of any plant and obtain the same desirable results. This, however, is not the case. The reason for this seems to be that we have not been able to work out methods of control in regard to large industrial furnaces along the same lines as we have been able to control the physical and chemical conditions of the small experimental furnaces in our research laboratories.

This lack of control on a commercial scale has been due to several reasons, the fundamental reason being our inability to control the combustion of the fuel in such a way as to definitely regulate at all times the furnace temperatures, uniformity of heat application, furnace atmosphere, and the other considerations necessary. This lack of control has been primarily due to the great difficulty involved in mastering the technique of efficient combustion and uniform heat application of the solid and liquid fuels.

Gas as a Fuel is Scientifically Correct

Gas is the ideal industrial fuel because the development of its heat energy and the application of that heat in any heating

process can be most accurately controlled. Gas delivered at a furnace is in the proper condition for its immediate development into heat energy.

The factors necessary for the complete combustion of gaseous fuel are known. The manner in which a fuel should be applied to obtain practically any condition desired is known. For these reasons, it is an easy matter because of the means we have for temperature control, to very definitely regulate the furnace temperatures desired. By proportioning the correct amount of air for the combustion of the fuel, we can obtain those atmospheric conditions in a furnace which are necessary for the highest quality standards of production. The other necessary conditions, such as uniform temperatures and desirable rates of heat transfer, are readily obtained.

If we make a survey of the industrial fuels available, we find that there are just two which satisfy this important factor of control. These two mediums are gas and electricity. From the scientific standpoint and from the standpoint of effective utilization, these two fuels are correct in principle. However, the fuel which will ultimately be adopted as the universal industrial fuel must not only be scientifically correct but the economics involved in its production, manufacture and distribution must be considered.

Electricity as an Industrial Fuel is Economically Unsound

From an analysis of these economic considerations a greater use of electricity for industrial heating operations is greatly limited. When we take into consideration the fact that electricity is produced from coal at a thermal efficiency of only about 10 per cent, we realize the great waste which takes place in using this medium for heating purposes. When we consider the fact that we first develop heat energy from the coal, then convert this heat energy into mechanical energy, then into electricity, and then turn this electricity back into heat energy, we can realize how unsound, how unsubstantial, how uneconomic the use of electricity as a fuel must be.

Furthermore, we have available no definite assurances that we shall be able in the future to produce electricty at much lower

costs than we do today. The recognized authorities of the electrical world claim that with the greatest innovations of equipment known today, the best we can expect from even a superpower development is an overall thermal efficiency of some 18 per cent. Certainly this figure does not justify us in considering electricity as the ultimate solution of our industrial heating problem, especially when we consider the high possible thermal efficiencies with which we can produce gaseous fuel from our low grade coals.

The Electric Versus the Gas Furnace

It is true that the electric furnace has made tremendous progress during the past few years, and it is true that it will make considerable progress during the next five or ten years. The reason for this is not because electricity is the best fuel available or that it represents the ultimate solution of the problem, but because the electrical industry has been first to realize the great achievements that could be accomplished in the industrial heating field. To be exact, the electrical companies have carefully analyzed the factors involved in any heating operation and have developed a furnace, considering at all times the characteristics necessary and the qualities necessary to perform those heating operations under the most desirable and at the same time most economical conditions.

The electric companies, by working together with the manufacturer, by first studying the problem from the scientific standpoint, and then developing the right kind of heating appliance for that work, succeeded in developing a number of furnaces which have resulted in giving the industrial plant an improvement and an accomplishment both from the standpoint of better quality and lower cost of production.

There is no question that the electric companies have rendered a very valuable service to the industrial heating world and that they should be complimented for this splendid work because they have given the manufacturer something better than he had before. While this is all true from the basic and economic standpoint, this is only a temporary condition. Perhaps this can best be brought out when we realize that the cost of electric energy runs three to five times greater than that of high-grade gaseous fuel, and fifteen to twenty times greater than our other solid and liquid fuels.

The progress of the electric furnace has not been due to the fact that the electric furnace is fundamentally correct, but it is because the fuel-fired furnace has been relatively so inefficient that the electric furnace, in spite of the almost prohibitive high price of electricity, was able to successfully compete with the inefficient fuel-fired furnace from the economical standpoint.

A New Type Gas-Fired Furnace

In order to bring out clearly just what is being accomplished in the way of developing gas-fired furnaces which will satisfactorily compete and displace the electric furnace, a few words will be said in regard to the gas-fired radiant element furnace. Due to the great advancements that have been made during the past few years in the development of high temperature refractories and high temperature resisting metallic alloys, it is now possible to construct an element made either of refractory or metal which will serve as a radiant heat source in exactly the same manner as the electric element functions today. This gas-fired element is fired internally and the heat is transmitted through the tube, through the element, and radiated from its outside surface to all parts of the furnace exactly in the same manner as is accomplished with the electric element.

This system of gas-firing can be applied to practically any kind of furnace operation and produce results similar to those obtained with the electric furnace in those operations where especially high quality standards of production have to be obtained and where neutral atmospheres in the working chamber are essential. With this gas-fired radiant element no flue gases enter the working chamber and, therefore, the same atmospheric conditions can be obtained as in the electric furnace.

While this type of gas-fired furnace is as effective and as exact as the electric furnace, its economies of operation are much greater. For example, on a basis of 2 cents per kilowatt hour for electricity and $1.00 per thousand cubic feet for gas, the operation of the gas-fired furnace will cost only about 40 per cent as much as that of a similar electric furnace. In addition, the first cost of the installation will be much less for the gas-fired installation.

In other words, with these developments taking place we can

readily realize the possibilities for the use of gaseous fuel. Not only will gas-fired furnaces which will give all the desirable conditions of the electric furnace, come into use during the next few years, but the cost of operation of these furnaces will be 50 to 75 per cent less than the cost of operation of the electrically heated furnace.

Gas is Economically Correct

Gas as an industrial fuel is not only fundamentally correct from the scientific standpoint but it also satisfies all the economic considerations involved. In regard to the raw materials available for the production of high-grade gaseous fuels, we have unlimited supplies. Generally speaking, our coal resources in this country on the basis of our annual requirements are sufficient to last us three thousand years.

The development of an efficient gas manufacturing process is only in its infancy. However, even today the methods used by central station gas companies operate on an overall thermal efficiency of from 50 to 80 per cent. During the past few years, much progress has been made in working out efficient and economic methods of producing high-grade gaseous fuels under very economical conditions. This entire development is just in the stage of realization, and we have very definite assurances that within the next few years, methods of producing high-grade gaseous fuel will be commercialized so that public utility gas companies of the United States and other countries will be in a position to supply gaseous fuels to the various industries in their communities at prices as low as ½ to ⅓ of the present prices.

It is gratifying to know of the great accomplishments that are taking place in working out methods of fuel processing, methods of low temperature carbonization and complete gasification, which will recover the valuable by-products of our low-grade coals and at the same time convert the bulk of the fuel into a high-grade gas, suitable for the performance of all heating operations. Not only is gaseous fuel highly desirable from the scientific standpoint, but its cost will become lower and lower, so that ultimately it will be the most desirable and economical fuel from every standpoint.

Vital Engineering Considerations Pertaining to the Effective Application and Efficient Utilization of Industrial Gas

While gas is a far more efficient and desirable industrial fuel

than either solid or liquid fuels, we must bear in mind that to capitalize upon its inherent advantages and use it effectively and efficiently, it is necessary to consider many factors to obtain the most desirable results. These factors involve several important considerations and when they are all given the proper thought from an engineering standpoint, it is possible to utilize fuel at the highest possible efficiency and economy. These important considerations are discussed in the following paragraphs:

Correct Air and Gas Proportions

To burn a unit volume of gaseous fuel of a definite British thermal unit value, requires a definite amount of oxygen which is obtained from a definite amount of air. The amount of air necessary for the combustion of a cubic foot of gas varies with the British thermal unit value and chemical composition of the gas. Whether a cubic foot of gas requires four, five or six cubic feet of air can be readily calculated.

The problem, however, is not so much in knowing how much air is necessary, as to be able to regulate the relative supplies of gas and air to the furnace so that the proper proportions are maintained at all times.

In the average plant we find a gas line and an air supply line. As the furnace operator turns on his gas, he attempts to regulate the valve on his air supply line so that he is using the correct amount of air. He has no definite means of control and in the majority of cases he is using either too much or too little air. In most cases he is using a large excess of air,—in many cases two or three times as much as necessary. This means tremendous heat losses, particularly in high temperature operations,—50, 100 or 200 per cent over-ventilation or excess air will mean the use of 50 to 100 per cent more fuel than necessary.

It is not only important from a standpoint of efficiency to use the correct amount of air, but it is also necessary from the standpoint of obtaining the correct furnace atmosphere in the working chamber. If gas is burned with too little air, its flame represents a reducing atmosphere. If gas is burned with excess air, the burning gases represent an oxidizing atmosphere. In the heat treatment or forging of steel and various other processes, it is essential to guard against oxidizing atmospheres, as the material

in the furnace is oxidized, which results in financial losses due to metal oxidation, metal loss, spoilage of material, etc.

The average operator of a furnace has not the knowledge nor the equipment to carefully regulate the correct proportions of gas and air. This can only be done from a practical standpoint by means outside of the control of the average plant man. It can, of course, be accomplished by putting pressure regulators on the gas and air lines, and then calibrating the gas valve against the air valve, so that whenever the gas valve is in a certain definite position the air valve will be in its correct position. This method works well, but it means a lot of expense due to the necessity of installing regulators and the installation of pipe lines for both the supply of gas and air.

While such an arrangement is of course possible, a better way of automatically proportioning the correct amount of air to gas so that at all times, regardless of the quantity of gas being burned, the correct amount of air is always available. Such an automatic arrangement is obtained through the use of an injector which uses the energy of the gas under pressure to inspirate the correct amount of air for combustion.

Such a system has, of course, many advantages. It not only provides for automatic proportioning of air and gas, but it also provides for automatic regulation of furnace atmospheres. Another advantage is the fact that in installing gas in a plant, it is not necessary to go to the expense of putting in costly air lines, blowers, etc. All that is needed is a small gas line going to the furnace. The burner equipment automatically inspirates air in the furnace in correct proportions.

Equipment which provides for the automatic proportioning of air and gas has been one of the greatest needs in the past. Systems to provide for this accurate control have been developed and are now serving in tens of thousands of industrial plants all over the world. The tremendous advantages of such a method have not only been recognized, but as time goes on its values will become more and more apparent, and it will be used to a larger and larger extent. No gas installation should be undertaken without giving thorough consideration to the use of equipment for automatic proportioning for air and gas.

Thorough Mixing of Gas and Air

In order to obtain complete combustion of gas and air, it is necessary for them to be intimately and thoroughly mixed. The lack of this consideration has proven to be one of the greatest shortcomings in the development of the gas furnace business. The sooner the gas molecules are brought into contact with the air molecules the quicker the heat energy is developed and the higher is the temperature of the flame produced.

The proper mixing of air and gas has not received sufficient attention, particularly on large furnaces where it was thought that the combustion chamber was sufficiently large to afford plenty of time for the gas and air to completely mix and burn. This has not been the case in many of the present large furnaces. The air goes through one inlet and the gas enters by another. No means are provided for intimate admixtures, with the result that the gas and air carry across the furnace chamber in layers, and in many cases the gases are not completely burned when they leave the furnace. Such a condition not only means enormous heat losses and waste of gas, but it means that there are enormous losses due to spoilage of material because a layer of hot air in a furnace is highly oxidizing and will oxidize materials in the furnace very rapidly.

In the past few years some installations made on large furnaces where provision was made for correct proportioning of gas to air and thorough mixing of gas and air, results were obtained from the standpoint of economy and efficiency which were almost unbelievable.

Better Insulation

We are just beginning to appreciate what can be accomplished in furnace efficiency when the furnace is properly insulated.

Several good insulating materials are available on the market and a thickness of an inch or two on a furnace will reduce heat conduction losses to an insignificant amount.

In the past our ability to insulate a high temperature furnace has been largely limited due to the fact that it was necessary to provide for a certain amount of heat loss through the refractory walls so that the inside surface of the refractory walls would not

get too hot and melt down. With the several recent developments in the field of high temperature refractory substances, we are in a much better position to go further in insulating furnaces, thus reducing these tremendous heat losses.

Recuperation and Regeneration

The nature of the combustion of gaseous fuel tells us that the burning gases must leave the furnace chamber at as high a temperature as the temperature of the furnace itself,—that is, if the furnace temperature is 1000 degrees Fahr. the flue gases must necessarily leave at 1000 degrees Fahr. or more. With a furnace temperature of 2500 degrees Fahr. the flue gases go up the chimney at 2500 degrees Fahr. or more.

Now what does this represent in heat loss? Generally speaking, flue gases going up the stack at 1000 degrees Fahr. carry away 25 per cent of the total heat in the fuel and at 2500 degrees Fahr. these flue gases carry away approximately 60 per cent of the total heat. Today we are burning gas and other fuels with such wastefulness, wherein very little attempt is made to recover this heat or to utilize it in some form or another. In most cases it is simply allowed to go up the stack and its heat value is entirely lost.

In a small way and in certain industries something has been done to save a portion of this heat by means of the continuous furnace and the installation of waste heat boilers which generate steam from these hot flue gases. A means of utilizing almost all of this waste heat is by the installation of recuperators or regenerators. They can be installed in an economical and practical manner on almost every furnace, whether large or small or operating at high temperatures or reasonably low temperatures.

In Europe, where the cost of fuel is very high, practically all heating operations which use appreciable quantities of fuel are equipped with either regenerators or recuperators to conserve the heat energy. In this country we find regenerators installed on many of our large industrial furnaces, such as open hearth and glass melting furnaces, but we must bear in mind that regenerators were not installed on these furnaces because of the desire to save fuel primarily. They were considered necessary for preheating the air and the gas so that sufficiently high temperatures could be attained when burning producer gas.

Up to the present time practically nothing has been done in the way of installing recuperators on furnaces. This development is just at the beginning. Much experimental work has been done in the development of recuperators, both in the form of refractory recuperators and those made from special high temperature resisting alloy materials. Both have their advantages for particular purposes. The metallic recuperator is used principally on small furnaces, while the refractory recuperators are desirable on large furnaces which operate at unusually high temperatures.

Recirculation of Flue Gases

In the combustion of gas with the greatest effectiveness there is another process which can be used to great advantage in a great many cases. This process is that of recirculating a portion of the hot flue gases which leave the furnace and mixing them with the air and gas for combustion, so that the burning gases really represent the combustion of the air and gas mixed with a certain percentage of the flue gases. By this method the cutting action and intensity of the flame can be reduced and the volume of the gases in the furnace can be increased and by this means obtain higher rates of heat transfer and more effective circulation of the hot gases in the furnace, resulting in avoiding overheating or localization of heat and producing better conditions of heat uniformity.

The Cost of Using Gas

The most economical and desirable fuel is the one which can be used at the lowest possible cost. The reason that gas is becoming recognized as the ultimate fuel and is coming into greater and greater use is because the cost of using it is much less than with any of the solid or liquid fuels. In every heating operation the cost per unit of production involves many factors of expense such as—first fuel cost, labor expense, furnace maintenance, material spoilage, etc.

If we have a fuel, the combustion of which we can control such as gas, we can properly regulate furnace atmospheres and furnace temperatures, so that the furnace maintenance item is a minimum and the loss due to material spoilage is reduced to practically a negligible item. With gaseous fuel we also eliminate

all the labor expense in regard to fuel handling, ash removal, furnace adjustment, etc.

With gaseous fuel we are in a far better position to reduce the cost of the heating operation by using more mechanical equipment than can be done where either coal or oil is used, because we can regulate the combustion and apply the heat exactly where it is needed. This is a most important fact in reducing the cost per unit of production.

Because of these many reasons, in the great majority of heating operations it is found that in the final analysis the cost per unit of production, where gas is used, is materially less than with either solid or liquid fuels. This is due to the fact that with gas considerable reductions can be effected in furnace maintenance, material spoilage, labor expense, and other important cost factors.

A Fuel Service by the Central Station Gas Plant

The great bulk of manufacturing plants do not use more fuel than the equivalent of fifty tons of coal per day, and from the study of the economics involved, it is easily realized that it is very undesirable and very wasteful for a small industrial plant to build its own gas producing equipment, because of the fact that it must necessarily have high fixed charges due to standby equipment, and that the operating charges must be nessarily high due to the relatively large amount of labor and other requirements necessary.

While the larger industrial plants of the country will find it desirable to have their own gas producing equipment, the most desirable thing and the ultimate solution of the problem lies in the direction of having the fuel requirements of the average industrial plant supplied by some central station gas producing organization.

As the author sees this problem, the public utility gas company of today will become the institution in each and every community which will supply all of the heating requirements of that vicinity. This will involve not only supplying gas for cooking purposes as is done today, but the gas utility will also supply gaseous fuel for househeating, and gaseous fuel to the industries for the operation of all heating processes. To the industrial plant this will be a great service. A high-grade gaseous fuel will be

supplied which will allow for the highest quality standards of production with the minimum of spoilage, and at the same time the price will be low enough to make the overall economics justified. Besides, the manufacturer will have the opportunity of devoting his time and energies solely to the operation of his own business and he will not be worried with the difficulties and idiosyncrasies of operating his own gas producing plant and the trials and tribulations connected with obtaining a continuous fuel supply, maintaining storage facilities, etc.

The ultimate solution of the industrial heating problem lies in the service the central station can render to the manufacturer by taking the responsibility of supplying him with a high-grade fuel at the lowest possible cost and in quantities as required by the industrial plant.

The Development of More Efficient Gas Furnaces

This discussion so far has dealt primarily with the possibilities and ultimate status of gas as an industrial fuel. However, the progress which has been made in the past few years has been such that it is well worth while to say a few words in regard to the development of better furnaces, and the good work that the gas companies are doing in lowering the industrial gas rates and giving the manufacturer a fuel service.

The manufacturer of gas-fired furnaces has begun to realize the tremendous possibilities of gas as a fuel, and has succeeded in developing many lines of equipment which represent distinct improvements in the art. Furthermore, the high degree of efficiency that has been obtained with the electric furnace has given the furnace manufacturer a direct objective and an indication of what can be accomplished in the way of building a highly economical and efficient heating appliance. It will not be long before gas-fired furnaces will be available on the market, which will not only be as desirable as the electric furnace, but will actually cost a great deal less in first investment and function with lower operating expenses.

Even today, in practically all fields of metallurgy, equipment is available which represents great advancement in furnace design, and which proves more desirable from an economic standpoint than either coal or oil-fired furnaces, and in many cases

the electric furnace. This is particularly true in the field of metal melting, forging and various heat treating processes of both ferrous and non-ferrous metals.

The Recuperative Furnace

There are several furnace companies today that are manufacturing equipment of this kind, using both refractory recuperators and metallic recuperators. These various equipments, generally speaking, represent a distinct advancement in the art; not only do they provide for greater efficiency in operation and general fuel saving, but the fact that preheated air is used for combustion, results in obtaining a flame of such characteristics, that more uniform temperature conditions are effected in the furnace, the temperature of the flame is higher, the production of the furnace per unit time is greater, and, generally speaking, the cost of production is reduced to minimum.

In a practical way, these theories have been so well demonstrated, that perhaps you will be interested in a few examples of what has been accomplished by recuperator furnaces during the past few months.

Greater Economy with Recuperative Furnaces

In a recent comparative test between an oil-fired furnace and a recuperator gas-fired furnace, the gas-fired furnace showed a fuel saving of 27 per cent, a greater production of forgings per unit time of 25 per cent, and at the same time the number of rejected castings was only 12 per cent of that of the oil furnace.

A comparison between a straight carburizing and a recuperator carburizing furnace showed a fuel saving of 38 per cent, and an increase of furnace production of 21 per cent. In applying recuperation to a heating furnace operated at 2000 degrees Fahr., a decrease in fuel consumption of 50 per cent was reported. Again, a recuperator heat treating furnace recently put into operation resulted in reducing the cost per unit of product from $1.71 to $0.99, indicating an actual saving in dollars and cents of 42 per cent. These various examples are simply a general indication of the results that are being obtained, and illustrate rather definitely just what can be accomplished in the way of better furnace effi-

ciency and economy by utilizing the modern methods of heat recuperation.

Lower Prices for Industrial Gas

Another factor in regard to the use of gas for industrial purposes which should be looked upon with interest by the industrial man, is the work that the gas companies of America are doing in order to be in a better position to give the manufacturer an industrial gas service.

Due to the fact that the heating load of the average industrial plant represents a much higher load factor than that of the domestic requirements of the average household, the gas company can afford to sell its product to the industrial demand at a much lower rate than to the domestic consumer, because the various fixed charges are much lower in the case of the industrial gas demand. Consequently, during the past few years many of our more progressive gas companies have made radical changes in their rates for the use of gas for industrial purposes, in many cases reducing the gas 30 to 40 per cent of what it was formerly.

We are now in a period when the gas companies of the United States are beginning to realize that it is one of their jobs to sell gas for industrial purposes, and from present indications there is every reason to believe that within the next few years the majority of the gas companies will work out industrial rates which will allow the manufacturer to purchase gas at a price from two-thirds to one-half of what it costs today.

Beside these improvements, the better methods of gas manufacture that are being developed also give assurance of lower costs of gas manufacture, resulting in lower prices to the consumer. Taking into consideration the installation of proper industrial rates, together with the cheaper manufacture of gas, there is not a question of doubt but that the ultimate cost of gas to the industrial plant will be no more than one-half of what it is today.

Gas the Ultimate Fuel

The day is fast approaching when the central station gas company will deliver gas for all the heat requirements of the community, involving domestic househeating and industrial heating.

Due to the use of better methods of gas manufacture, and the fact that gas will be produced and sold in far greater quantities than today, the price will be far below what it is at the present time.

This factor, coupled with the installation of industrial gas rates and the development of better utilization equipment, as well as the general service that the gas company can give the consumer, will result in giving the manufacturer a fuel service which will allow him to carry on his operations under the highest quality conditions and lowest possible cost without any worry on his part as to the uncertainties of fuel supplies, storage facilities, fire hazards, unsanitary conditions, etc. All these factors, including supply, quality, continued service, etc., will be taken care of by the gas company.

Certainly there is nothing more satisfying to the manufacturer than to know that he has available a fuel that will allow for production under the highest quality conditions and at the lowest costs,—a fuel which is at the same time permanent and will, as time goes on, decrease rather than increase in price.

Discussion of Papers

CHAIRMAN BOYLSTON: I want to thank the speakers for their presentations. The meeting is now open for discussion.

H. E. SCARBROUGH: With regard to Mr. Loebell's reference to the electric furnace being compared to inefficient gas furnaces, I know of a very specific instance which I would like to bring to Mr. Loebell's attention. In Chicago some months ago we had an opportunity to make a comparative test in a very practical way in a manufacturing plant. The General Electric Company and the Commonwealth Edison Company of Chicago conferred with representatives of this company and agreed to put in an electric furnace on trial. We put the electric furnace in, and then the People's Gas Light and Coke Company obtained permission from this manufacturer to put in a gas furnace, well insulated, enough burners to give uniform temperature, and automatic control. They put the furnace in and set it up beside the electric furnace. These furnaces have been running for a year. The electricity to run the electric furnace to do a certain job is 20 per cent less than gas; that is, one cent electricity and 75 cent gas.

D. L. COLWELL: I would like to amplify the last speaker's remarks a little bit further. In the Stewart-Warner Speedometer plant at Chicago the General Electric company has installed a resistor-type electric furnace, suitably insulated. The People's Gas Light and Coke company installed a similar gas furnace, about the same size. This gas furnace is heavily insulated and is equipped with a recuperator, and I believe is using gas under pressure,

sucking the air in. Mr. Loebell may know more of the details and the results of the test than I do at the present time, but the original cost of the equipment, taking into consideration the auxiliary equipment necessary with the electric furnace and the recuperator and blower, etc., necessary for the gas furnace, were nearly the same. The electric equipment is generally considered more expensive, but when one installs all of the accessories necessary to save the B. t. u.'s in the gas furnace, the cost runs up just about as high. These furnaces have not been in operation long enough, particularly over the summer slack season, for me to have the figures available as to which is proving the better. It appears, however, that there is not such a great diffrence in the cost of the fuel, and when they are correctly operated, particularly the gas furnace, there is not such a great difference in the quality of the product. The test will have to run for some time to determine definitely which is the most economical, and I am sure that the People's Gas Light and Coke company at Chicago and the General Electric company will both have the figures when the test is completed.

S. P. ROCKWELL: I want to read some observations taken on small heat-treating units, in comparison with some data taken from electricity and gas as fuels. This probably does not cover all the field, as it is mostly derived from small units.

For fuel economy an electric furnace must needs be equipped with an automatic heat controller. Leaving out the cost of the furnace itself, electric heat controller relays, etc., are more costly than the corresponding diaphragm valves of a gas heat controller.

An electric furnace may be controlled by a simple rheostat. A large amount of electric energy is, however, dissipated in the rheostat itself. This, with the electric energy used by the furnace, makes electric fuel-cost prohibitive, without the automatic controller.

A gas furnace may be run with or without a heat controller with the same degree of fuel economy. The advantage of the heat controller is that it saves labor, and requires no attention to maintain close limits of temperature.

The electric furnace atmosphere is oxidizing. This means that steel heat treated in this atmosphere will scale. Non-deforming, oil-hardening and chrome steels for this reason are seldom satisfactorily hardened in an electric furnace.

It has been shown that next to temperature, the atmosphere in which the heating takes place is of prime importance.

In a gas furnace with or without heat control, any atmosphere from oxidizing to neutral to reducing demanded by the type of work heat treated may be had at all times. This is irrespective of gas or air pressure or temperature.

In lead, salt and carburizing furnaces, atmosphere is of importance only as it affects the containers, pots and boxes.

A statement is made that an electric carburizing furnace will carburize the articles packed in any size box to the same depth; this whether they be on the outside or at the center of the box. Such a statement is true only so long as the heating rate of the furnace itself is but a few degrees hotter at all

times than the outside of the boxes containing the work. A gas furnace can be manipulated in the same way. It is easy to see that with any fuel, such manipulation to obtain the results of even depth will require an excessive period of time in raising the boxes and contents to full carburizing temperature. The only method by which all of the work in the load can be raised evenly and quickly to heat is by the well known rotary carburizing method.

To secure reasonable fuel economy in an electric furnace, a great wall thickness of insulating brick work is necessary. The non-reasoning man will place his hand on the outside of such a furnace when in operation and because it is reasonably cool he figures it is far superior to a gas furnace lacking such great insulating qualities. Heavy wall thicknesses or insulating material take up floor space.

Economy in electric furnaces, figuring fuel costs, equipment costs, etc., can only be economical when they are sealed up for long periods of time. Such furnaces would be carburizing furnaces and annealing furnaces in which the operation is of at least 12 hours duration. This allows securing of low, night power rates.

Furnaces in which the doors must be opened at fairly regular periods to handle the work, lead or salt furnaces in which a minimum of at least a sixth of the pot (plus the tendency of heat to rise vertically)) is exposed to direct radiation to the air, are far from being equal to gas in fuel economy.

Electric heating elements are made of a heat resisting alloy ribbon or wire. Repairs when burned out often cause serious holdup to production, the presence of a specialist, and great expense. A gas furnace hardly ever needs to be shut down entirely in a rush period. Temporary repairs can be made by inexperienced labor in a few moments, and any mechanic can make permanent repairs, or install relinings in a few hours.

The heating elements in the elecrtic furnace are destroyed through scale from carburizing boxes or annealed work, bone dust, leaky lead pots, or the action of salt fumes. None of these conditions are detrimental to the gas furnace.

Nothing can be said concerning cleanliness as regards the electric furnace over the gas furnace.

An electric furnace offers no advances as to distribution of heat uniformity than a gas furnace. In each case it is merely a question of good design.

Often and regrettably in production work, speed is held as primary importance. In many cases this is entirely permissible. The electric furnace, however, cannot be pushed as can a gas furnace.

It was stated that often the feel of the outside of the furnace is accepted as an indication of its desirability. This is only so as regards fuel economy. The advantage of heavy insulation decreases, from the standpoint of close control limits and control ease, as radiation aren increases. Such radiation area applies to open furnace doors and open lead and salt baths. Too heavy insulation is especially undesirable in the case of lead or salt baths when the fire end, which signals the temperature of the control pyrometer, is immersed in the bath. The heat generated in the heating elements in the electric fur-

nace takes a period of time to pass through the air surrounding the pot, through the pot and thence through the bath. By the time the lead is at the desired temperature and the current cut off, the brick work near the heating elements has been heated much in excess of the lead temperatures. Though the source of heat has been removed, the excess heat in the brick work causes the lead temperature to rise. It is seen that fineness of control is thus sacrificed for fuel economy.

As gas is the cheaper fuel, a better balance between fuel economy and fineness of control is more practical.

The above is one reason why the automatic gas control on a gas furnace is more accurate than electric control.

A belief seems to exist that in all cases electric control can be secured to a smaller number of degrees plus or minus than with gas control. This on the face is untrue. The pyrometer is the part of the controller that tells when to turn on or off the fuel supply. The same type of pyrometer is used on both electric and gas heat controllers.

It must be remembered that with the electric furnace and heat controller, the fuel is either all-on or all-off. The gas furnace and heat controller, on the other hand, allows the mixed air and gas to be lowered or raised within any limit found desirable.

W. S. Scott: There are many of the largest companies in the United States where they know exactly what their operating costs are, who have gone into the thing thoroughly. They are not interested in discussing the value of a lump of coal, whether it contains 14,000 B. t. u.'s or 78,000, or whether the efficiency of a boiler at a central station is 30 per cent, 20 per cent, 60 per cent, or 80 per cent. What they are concerned with is the over-all cost of the completed product. These companies who have these 1,250,000 kilowatts of industrial heating have gone into the situation and have satisfied themselves that it is an economical proposition for them.

There is one thing that I wish to emphasize. It is this. Electric heating is here, and it is here to stay. It is something given to the people to work with which is far superior to any other method of heating on the market. Industrial heating at the present time is being developed in the same manner that the electric motor was developed. I was in the electric motor business some twenty years ago, and I remember the uphill road we had to travel. In a certain city in Ohio where they were selling natural gas for 25 cents a thousand cubic feet, we had to get in and develop a motor business. At that time the power for the electric motor was costing from six to eight times the cost of the gas for the equivalent gas engine. But you go to the same city today and you cannot give a gas engine away, for operating plants. The electric power has decreased in cost, whereas fuel has increased in cost. But in those days we succeeded in getting a toe-hold, just as we are doing now with industrial heating. There has been a lot of discussion here on the cost of the B. t. u. and comparative costs, as to what it costs to generate in a power station, etc. I say you can forget all that. You do not need to know or care what the B. t. u. cost is, if you are buying central station power, or if you are not, your management knows what your power cost is at the switch-

board, and if you can buy central station power for one, two, or three cents, you have a right to assume that that particular central station furnishing that power is making a profit on it, and can afford to sell you power at those respective costs, and you do not need to worry or care about whether or not the efficiency of that plant is 30 or 60 per cent.

H. J. N. VOLTMAN: Going back to Stanley Rockwell's discussion I feel that it is in order to come to the defense of electricity. Personally, I feel that Mr. Rockwell has spoken from a rather unfamiliar viewpoint insofar as electricity is concerned, because he has told you just one or two of the points involved. He has told you that the only way that electricity may be controlled, outside of an all-on and all-off control is by means of a rheostat that wastes a great deal of current. I wonder if Mr. Rockwell knows of the expedient of a tapped auto-transformer that will enable one to utilize as many varying voltages as he wants with practically no rheostat losses. I wonder also if he is familiar with the type of electric furnace with windings so arranged that some heat could be kept on all the time; of an electric furnace that might be arranged with automatic contactors controlling various auto-transformer taps, so the current input into the furnace would be at all times in ratio to the amount that was being absorbed by the stock. These are some of the things that he has set up as against electric furnace equipment, and in favor of gas, that I think you ought to know about. We are all too prone to adopt a viewpoint that the particular thing we are speaking for is the only thing that can be used for a certain purpose.

A. H. D'ARCAMBAL: My good friend Stanley Rockwell made a statement that you could not harden tools in the electric furnace if they were made of bearing steel or oil hardening steel. Is that correct?

S. P. ROCKWELL: Answering your question, Mr. d'Arcambal, and that of the previous speaker, I tried to make it clear that I made reference to the small-type electric furnace. I am familiar with the type of transformer control that you speak of, but we do not find many of them in our locality. They are seen to a greater extent on the larger equipment. But there are many small plants that have a small bench furnace, and they use a little common rheostat on it. Now, with regard to your question, Mr. d'Arcambal, there are one or two steels that I have not seen successfully hardened in electric furnaces without getting the skin softness. It can be done by putting in charcoal and changing the atmosphere in the furnace, but in the pure oxidizing atmosphere in the furnace I have not seen these steels hardened successfully.

A. H. D'ARCAMBAL: We have a pretty good sized furnace and it is operating successfully. As yet we have not experienced trouble due to soft spots.

I believe you also stated that it was more difficult to control the temperature of an electric lead-pot furnace than with a gas fired lead-pot furnace. I should think more heat would be stored up in the gas-fired furnace due to the high temperature of the gases, thus making it more difficult to control the temperatures.

S. P. ROCKWELL: In regard to the lead pot and the salt bath, you usually will find the gas furnace type with the less insulation. It is the heat energy stored up in the brick work itself, and the necessary transmission through the

air to the pot, through the lead to the thermocouple which causes large plus and minus variations.

A. H. D'ARCAMBAL: In our electric lead pot furnaces the space between the pot and the resistor is about one inch. I believe the temperature of the resistor is usually 200 degrees higher than the temperature of the lead bath.

S. P. ROCKWELL: I think the variation in your furnace is around plus or minus 15 degrees. I believe with the gas furnace, with less insulation, you can control the variations better.

A. H. D'ARCAMBAL: The makers guarantee plus or minus five degrees Fahr. We consider that for the ordinary work plus or minus ten degrees Fahr. is all right.

Some of the articles one reads are very misleading. I believe it was in "Fuels and Furnaces" that an article came out where they spoke of an electrically heated oil tempering bath where the temperature of the oil near the heater reached 2,000 degrees Fahr. We checked that up and found we had a difference of only fifteen degrees between the temperature of the oil near the heater and the temperature of the oil near the surface. It is to one's advantage to check up statements that do not appear reasonably correct.

HAAKON STYRI: In our laboratory we do all our experimental heat treatment work in the electric furnace, and if we were in any trouble from hardening, we would certainly experience that right away. The accuracy is plus or minus five degrees.

It may also interest you that we have an automatically controlled furnace where we may throw the heat in from the back, and an oil fired furnace where we also have plus or minus five degrees in temperature.

F. J. EVANS: I just want to follow out Dr. Styri's talk and advise you that we have in use automatic gas-fired furnaces on bearing work that are not in the laboratory, but on production, handling all the production in one bearing plant. These furnaces are automatically controlled, as well as automatically fed, and they control the temperature within plus or minus five degrees. It can be controlled with as heavy insulation on this furnace as the electric furnace has on it. It also can be done in a lead pot constructed with heavy insulation by means of a double thermocouple connection, one in the lead and one in the combustion chamber. Using this arrangement, absolute control can be maintained, because the temperature is being used at both points.

F. C. TAYLOR: In buying automobiles you do not consider simply the cost of gasoline per ton mile. For a long time we have heard this B. t. u. argument used furthering the sale of different types of equipment. I do not believe that simply because coal is one of the cheapest of raw materials, either the gas or electric industry wants to favor the use of coal as a fuel simply because the cost per B. t. u. may be made lower than that of gas or electricity without considering the overall cost of the process and many other factors. Of course, if you used coal you would save your investment in electric generators, distribution lines, and in the same way for gas you would save your cost of generating equipment, pipes, the necessary holders, etc. The B. t. u. theory is being exploded rapidly, I believe. I might also state that I am a

representative of a central station that sells both gas and electricity. Also that the department selling to the industry both gas and electricity is under the same head, that is, the head of the department controls the sale of gas and electricity to the customers. He recommends the equipment. We do not believe in selling gas equipment exclusively, neither do we believe in selling electric equipment exclusively. As has been said here, we believe that each fuel, gas, electricity, or other heating medium, has a field of its own. Now, I might say just one other thing, with apologies, but I have got to say it just the same, and that is that the best salesman indicates to the customer the advantages of his equipment over other equipment, not necessarily mentioning any names, but particularly stating what his equipment will do, stating that his equipment will do a very good job, at low cost. Therefore we try to satisfy the customer, not with any one panacea, but by trying from our intimate knowledge of both gas and electricity, to sell the device that is best fitted for his use; and which will give the best product at the lowest overall cost.

Let us forget the B. t. u. and forget the fights between gas and electricity. Each one has a broad field, each one can learn from the other. Let us go out and sell to the customer the device best suited for his needs.

A. H. D'ARCAMBAL: Mr. Chairman, the gentleman who just spoke is in such a unique position, it might be interesting to learn from him the fuel which has met the greatest favor during the past year. Is more gas used than electricity, or would you be unwilling to answer that question?

MEMBER: I can state authentically that the industrial use has increased 25 per cent in the United States in the last year. Industrial gas increased 50 per cent over electricity.

F. C. TAYLOR: I cannot give that in figures. I do not know what you mean, because it is difficult to compare kilowatt-hours and cubic feet of gas. I might say that in the last year we sold about 1500 kilowatts of electricity, installed capacity, for use in core ovens, carburizing furnaces and heat treating furnaces, and gas has also been very successful in vitreous enameling, large annealing furnaces, and also in japanning.

A. H. D'ARCAMBAL: When a new company starts up or rebuilds their hardening room, are they going to use electricity or gas?

F. C. TAYLOR: I made the statement definitely that there is no one panacea for every plant. In one plant, owing to its size and buying electricity wholesale, they might get a very low rate for electricity. Also, in the core baking process, which ordinarily is night baking, a still lower rate for electricity may be obtained. So it is rather difficult to state these advantages without some gas or electric man getting up and saying they are not so. I will merely state the advantages of one fuel over the other, outside of the cost per B. t. u., will determine in each case what should be the type to go in, and I am not neglecting the first cost, either. You have got to be broad-minded on the subject of putting in equipment in a plant rather than being narrow-minded and thinking merely of gas and electricity in terms of cents per kilowatt-hour or cents per thousand cubic feet of gas.

J. H. FRIEDMAN: I would like to ask the gentleman who just spoke what factors his salesmen, or rather, his company's engineers, take into considera-

tion when they recommend one fuel against another. A summary of those factors would be of extreme interest to many of us.

F. C. TAYLOR: I do not like to take the time to do that. I think if you will take any gas catalog or read any list of papers, you can get the whole thing. Mr. Loebell's arguments, and Mr. Collins' I believe will give that information.

E. C. COOK: In answer to the question raised by Mr. d'Arcambal as to the possibility of very high temperatures in oil tempering baths, I would say that Mr. Ogur, whose article is under discussion, reiterates that a careful temperature exploration reveals temperatures of approximately 2,000 degrees Fahr., near the immersed electric heating units. A heavy pitch-like composition formed on the coils which were located deep down in the oil, and a heavy deposit collected at the bottom of the tank. Under these circumstances, I see no reason why Mr. Ogur's statement regarding temperatures found should be questioned. Complete discussion of his article will appear in an early issue of "Fuels and Furnaces."

E. F. COLLINS: I have been thinking as I sat here listening to these expressions of uncertainty, and feel that when you read my paper, you will find I said that I believed the thing for the metallurgist and the management to do, was to engage a competent engineer and let him decide what type of heat should be used. That is the one thing that I have been trying to get across for a long time, and if you will do that, you gentlemen will soon have dissipated all these uncertainties and be on a solid, substantial foundation. Put your problem up to the real furnace engineer and let him decide it. If he decides it shall be gas, I will agree that it should be gas. If it is oil, it ought to be oil. If it is electricity, let it be electricity. But this analysis which determines what you ought to use is not so simple as some of you may suspect who have not studied the question quite as much as some of us. Mr. Doyle's chart purports to give you a partial list of the things to be considered by an engineer in deciding the question.

Just because John Smith over here is using electric furnaces in his plant with success, I would not go in a plant in another quarter of the city and unqualifiedly recommend electric furnaces for him, just because they are being used in John Smith's plant, because there are so many elements to be considered. And if you will note in my paper, my whole plea is that we get a correct and complete analsyis, such an analysis as is made by an impartial and competent engineer.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 142. *What is the consensus of opinion of the cause of blisters in low and high grade steel sheets?*

QUESTION NO. 143. *How can these blisters be eliminated?*

QUESTION NO. 144. *Why do many chromium-nickel steels show a laminated structure when viewed under the microscope?*

QUESTION NO. 145. *How will the cutting qualities of a lathe tool made from an* 18 *per cent tungsten steel be affected by quenching from* 2400 *degrees Fahr. and tempered at* 1100 *degrees Fahr. as compared with a similar tool quenched from* 2300 *degrees Fahr. and tempered at* 1100 *degrees Fahr.?*

ANSWERS TO OLD QUESTIONS

Question NO. 120. *How does the carbon content affect the secondary hardness of high speed steels?*

ANSWER. By Marcus A. Grossmann, research metallurgist, United Alloy Steel Corporation, Canton, Ohio.

The carbon content of high speed steels affects their hardness to a very marked degree. The average high speed steel contains about 0.65 per cent carbon, and the range of usefulness above and below this figure is quite limited.

When the carbon content is reduced, the hardness obtainable after heat treatment decreases, and that so rapidly that practically no high speed steel is used with less than 0.60 per cent carbon. On the other hand, when the carbon content is raised, the steel becomes sensitive in manufacture and in heat treatment, so that very little of it is used with more than 0.75 per cent carbon. (This all refers to the high tungsten steels with 18 per cent tungsten, 4 per cent chromium and 1 per cent vanadium). The carbon range of useful high speed steels for cutting tools is therefore about 0.60 to 0.75 per cent.

Since the useful range for carbon is so limited, it is not surprising to find that a comparatively small change in the percentage of carbon affects both the initial hardness (on quenching) and the secondary hardness (on drawing

at 1100 degrees Fahr.) The higher carbon steels are harder in both instances. With 0.60 per cent carbon, the highest hardness obtainable by a quench at 2350 to 2400 degrees Fahr. is about 65 Rockwell-C. This is just over "file-hard." The secondary hardness after an 1100 degree temper is about the same. With 0.70 per cent carbon a quench at 2350 degrees Fahr. will give about 67 Rockwell-C, with about the same after an 1100 degree temper; it is usually amply file hard. A reservation must be made in connection with the last statement: the other alloying elements (tungsten, vanadium and also molybdenum) must not be too high, otherwise a carbon content of 0.70 per cent will not be sufficient to produce "file-hardness."

QUESTION NO. 134. *What are the usual feeds and speeds used in machining both carbon and alloy automotive steels, when using high speed steel cutting tools?*

QUESTION NO. 135. *From what material should the gears and pinions be made to be used in a galvanizing bath, that is, operated under molten zinc?*

ANSWER. By J. H. Nead metallurgist, American Rolling Mill Co., Middletown, Ohio.

We have found from long experience, that commercially, pure iron is less soluble in a galvanizing bath of molten zinc than steel, therefore, all of the gears and pinions on our galvanizing machines which are immersed in molten spelter are cut from forgings made of Armco ingot iron. We have found that this material gives much greater life than steel gears. Other galvanizers have also had this same experience, and we furnish forgings for gears for galvanizing machines to a number of galvanizers.

QUESTION NO. 136. *Which is the best pot for sheet galvanizing, one built up from heavy boiler plate, or a cast pot? If a cast pot, about what analysis?*

ANSWER. By J. H. Nead, metallurgist, American Rolling Mill Co., Middletown, Ohio.

It has been our experience that the best pot for sheet galvanizing is one built of heavy boiler plate. Our pots are riveted and are made of quite heavy material, the side walls being about 1½ inches thick and the bottom about ¾ inches thick. Cases of leakage are very rare and when they occur the leaks are stopped by welding. We do not use cast pots, but find that the riveted pots made of heavy boiler plate are satisfactory.

QUESTION NO. 137. *What is the mechanism of the iodine etch for the deep etching of steel?*

QUESTION NO. 138. *Is the electrolytic pickling process being used to*

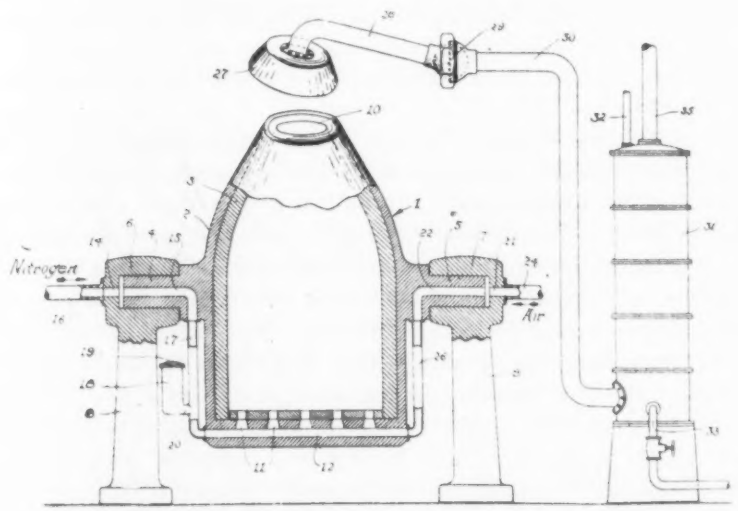
(Continued on Page 142)

Reviews of Recent Patents

By
NELSON LITTELL, Patent Attorney
110 E. 42nd St., New York City
Member of A. S. S. T.

1,505,281, **Process for the Manufacture of Steel and the Fixation of Nitrogen. Adriaan Nagelvoort, of Providence, Rhode Island, assignor to the Nitrogen Corporation, of Providence, Rhode Island, a corporation of Rhode Island.**

This patent relates to a process for the manufacture of steel and the fixation of nitrogen. According to the process outlined, an ordinary Bessemer converter consisting of an outer shell 1, a refractory lining 3, blast pipe 12, tuyeres 11, etc., is used in carrying out the process. The converter is tiltable in the trunnions 8 as in the ordinary construction and is provided



with an air blast connection 24 for forcing the blast into the base of the converter. On the opposite trunnion, a second blast connection 16 is provided which may be connected with a suitable source of nitrogen under pressure so that in the operation of the process nitrogen may be forced into the molten metal of the converter from the tuyeres 11. The converter is charged with molten metal in the usual way and is subjected to an air blast from two to four minutes to remove the silicon and other impurities from the metal and raise the heat of the metal to a degree at which the combination of nitrogen and carbon readily takes place. At the end of this time the air blast is turned off and simultaneously therewith a supply of nitrogen under pressure is forced from the conduit 16 and tuyeres 11

through the molten metal. During the use of the nitrogen blast, an alkali metal, such as vaporized sodium is introduced into the conduit 17 from the container 18 to assist in the reaction between the nitrogen and the carbon of the molten metal to form cyanogen compounds. During the period that the air blast is in operation, the top 10 of the converter is opened to the air so that the gases may escape therefrom. When, however, the nitrogen blast is turned on, the top 10 of the converter is closed by the hood 27 and the cyanogen gases are conducted through the pipes 28 and 30 to the scrubbing tower 31 where suitable reagents may be admitted through the pipe 32 to dissolve and carry off the resulting products through the pipe 33. In this way, by using the nitrogen to remove the carbon from the metal in the converter the usual grade of Bessemer steel may be produced and a very valuable by-product resulting from the union of the nitrogen and carbon is also produced which reduces the cost of steel. The supply of nitrogen may be produced by the liquefaction of air and the oxygen produced thereby may be used to enrich the air blast of the blast furnace.

1,502,642, Method of Making Manganese Steel, Richard D. Jordan and John H. Hall, of High Bridge, New Jersey, assignors to Taylor-Wharton Iron and Steel Company, of High Bridge, New Jersey, a corporation of New Jersey.

This patent relates to the production of commercial manganese steel in electric furnaces. Instead of melting the carbon scrap together with lime under oxidizing conditions and then, after adjusting the carbon, deoxidizing the slag and adding the ferromanganese, these inventors produce commercial manganese steel from low phosphorus carbon steel scrap by adding at the outset, before melting, sufficient ferromanganese to produce with the carbon scrap, finished manganese steel, and melting the same together with a small amount of lime and silica sand under non-oxidizing conditions. As soon as the bath is melted, the heat is brought rapidly to the tapping temperature, working the slag with a deoxidizing agent. Final adjustments of the carbon manganese and silicon are made just before the heat is tapped. The same procedure may be followed with manganese steel scrap, by introducing the smaller amount of ferromanganese necessary to bring the manganese content to the desired figure. The inventors prefer to have the silicon content above 0.35 per cent and preferably above 5.50 per cent. If necessary, the silicon content is raised by the addition of ferrosilicon.

1,506,894, Alloy Steel and Process of Making the Same, Charles Tyndale Evans, of Titusville, Pennsylvania.

It is the object of this patent to provide an alloy steel for cutlery which is substantially non-corrosive and which at the same time is readily worked and may be satisfactorily hardened at a temperature of about 2000 degrees Fahr. A preferred composition is, carbon 1.00 per cent, chromium 6.00 to 7.53 per cent, and tungsten more than 4.00 per cent, to which may be added a small amount of manganese, silicon, not more than 2.00 per cent, and nickel in substantial amounts. In the production of cut-

lery or other articles of this material, the ingredients are mixed with the desired percentages of iron, chromium, tungsten, manganese and silicon, together with zirconium, cerium and titanium, melted, and then worked into the desired article, and hardened at a temperature high enough to develop the non-corrosive properties, namely, around 1900 to 2000 degrees Fahr.

1,507,452, **Zirconium Steel and Process of Making Same, Frederick M. Becket, of New York, N. Y., assignor to Electro Metallurgical Company, of New York, N. Y., a corporation of West Virginia.**

This patent describes a process whereby a high sulphur steel may be used without exhibiting "red-shortness". The detrimental effect of the sulphur is overcome by adding to the steel, zirconium in amounts of 0.15 to 0.50 per cent, calculated on the weight of the steel. The invention, in overcoming the detrimental effects of the high sulphur content in the steel, will permit the use of a greatly increased quantity of coal of high sulphur content for coking purposes, and also make available for steel production a large tonnage of pig iron and scrap, which is now considered off-grade because of high sulphur content. The zirconium is preferably added in a ladle in the form of silicon-zirconium in the amounts necessary, and is believed to enter into a chemical combination with the sulphur, which eliminates the tendency of the sulphur steel toward "red-shortness".

1,507,845, **Carburizing Compound and Process of Making and Using It, Stanley B. Mathewson and Walter K. Jamison, of Springfield, Ohio, assignors to Walter K. Jamison, Stanley B. Mathewson, Howard F. Marston, Mrs. W. K. Jamison, and Mrs. S. B. Mathewson, trustees of the Lecar Carbon Company, a Trust Estate, of Springfield, Ohio.**

This patent describes the process of case hardening steel, utilizing scrap leather which has been carburized by being heated in closed cans to 1200 degrees Fahr., and permitted to cool slowly in a closed furnace. The carbonized leather is then crushed, ground and used as a packing in a case hardening process.

1,508,032, **Corrosion-Resisting Ferrous Alloy, William H. Smith, of Cleveland, Ohio, assignor to Ludlum Steel Co., of Watervliet, New York, a corporation of New Jersey.**

This patent discloses an alloy of malleable, soft steel with resistance to corrosion and oxidation at elevated temperatures. A typical analysis of the alloy is, chromium 18.00 per cent, manganese 1.50 per cent, silicon 1.00 per cent, titanium 0.20 to 0.35 per cent, aluminum 0.03 per cent, phosphorus and sulphur less than 0.05 per cent, and the balance, iron and carbon. The titanium acts as a scavenger and deoxidizer, and appears to assist in the removal of nitrogen into the slag.

News of the Chapters

STANDING OF THE CHAPTERS

THE relative membership standing of the 29 chapters of the Society as of December 1st appears below. Comparing this list with that of November 1st, as published in the December issue of TRANSACTIONS, it will be observed that there are comparatively few changes in the order. No changes of order appear in Group 1, although there have been small changes in the actual membership count. The Lehigh Valley chapter advanced from Group III to Group II and holds second place in this group. In Group III, the Springfield chapter advanced from next to the last position to the 7th position.

I	II	III
1. Detroit (282)	1. Hartford (130)	1. New Haven (55)
2. Pittsburgh (274)	2. LEHIGH VALLEY (102)	2. Tri City (55)
3. Chicago (265)	3. Golden Gate (101)	3. Worcester (49)
4. Cleveland (249)	4. Syracuse (79)	4. Los Angeles (48)
5. Philadelphia (224)	5. Milwaukee (77)	5. Washington
6. Boston (219)	6. Cincinnati	6. Schenectady
7. New York (203)	7. Indianapolis	7. SPRINGFIELD
	8. Buffalo	8. South Bend
	9. Northwest	9. Rockford
	10. St. Louis	10. Rochester
		11. Providence
		12. Toronto

BOSTON CHAPTER

The Boston chapter of the American Society for Steel Treating held a meeting on Thursday, December 18th, at Massachusetts Institute of Technology at 8:00 p. m. Supper was served in the Walker Memorial Building at 6:30 p. m. with an attendance of 95 members and guests. A special attraction was made for the period directly following the supper and before the meeting, in a visit to the Department of Naval Architecture in the Pratt Building and an inspection of their exhibit of ship pictures, there being models and pictures of every type and style of vessel from the beginning to the present day. The speaker of the evening was Mr. A. H. d'Arcambal, metallurgist for Pratt & Whitney Co., Hartford, Conn., whose subject was "Carbon Tool and High

Speed Steels used in the manufacture of Small Tools.'' An attendance of 124 members and guests were present to listen to Mr. d'Arcambal's talk, and a very interesting discussion was carried on throughout the entire evening, interrupting Mr. d'Arcambal with questions, and following the talk the discussion dealt the heat treatment of all forms of tool steel. Mr. d'Arcambal had with him a very excellent and varied selection of samples illustrating the points brought out in his talk as to the selection of steels for the manufacture of tools, hot etching samples, fractures of all kinds, and tools themselves, illustrating the designs and even the ''Graveyard,'' illustrating what a metallurgical department can sometimes find. This was one of the finest meetings ever held by the Boston chapter.

CHICAGO CHAPTER

The regular monthly meeting of the Chicago chapter of the American Society for Steel Treating was held on Thursday, December 11th at the City Club. E. J. Janitzky, metallurgical engineer with the Illinois Steel Works, was the speaker of the evening, choosing for his subject, ''Heating Problems.'' This was a practical talk, and was of much interest as evidenced by the lively discussion which followed. Dinner was served at 6:15 p. m., preceding the meeting.

CINCINNATI CHAPTER

On December 11, at 8:00 p. m., the Cincinnati chapter of the American Society for Steel Treating held a meeting in the Ohio Mechanics Institute, at which time W. S. Bidle, president of the W. S. Bidle Co., Cleveland, and first vice-president of the Society, gave a practical talk entitled, ''Planning a Heat Treating Plant.'' Various types of equipment were discussed as well as problems which are encountered in the planning of a heat treating plant.

CLEVELAND CHAPTER

The fourth regular monthly meeting of the Cleveland chapter of the Society was held in the rooms of the Cleveland Engineering Society, Friday, December 19th, 1924, at 8:00 p. m. An excellent paper on ''The Strong Alloys of Aluminum'' was presented by R. S. Archer, metallurgist of the Aluminum Co. of America and former chairman of the Cleveland chapter. Mr. Archer described the various types of alloys developed during recent years in response to the demand for aluminum of high tensile strength, and discussed their composition, heat treatment and properties. He gave the exact heat treatment used for each of the alloys and presented figures to show the resulting tensile strength and elongation. The three alloys chiefly considered were the ''duralumin'' type, the aluminum plus 4 per cent copper type, and the aluminum-magnesium-silicon type. The theory of the aging and other remarkable properties of these alloys was discussed, and a practical demonstration was given to show the strength and toughness of test bars of the

newer alloys as compared with ordinary aluminum. Many samples of parts now made from cast and forged aluminum alloys were exhibited. An extended discussion followed the lecture and demonstration. Dinner was served in the hotel dining room at 6:45 p. m. preceding the meeting.

DETROIT CHAPTER

Prof. W. P. Wood, chemical engineering department of the University of Michigan, was the speaker of the evening on the occasion of the meeting of the Detroit chapter of the American Society for Steel Treating, which was held at 8:00 p. m., December 15th, in the General Motors Building. The subject of the speaker's address was "Causes and Controlling Factors in the Corrosion of Iron and Steel." Prof. Wood has made an intensive study of this subject, and his paper was of exceptional interest to all, being illustrated with lantern slides.

GOLDEN GATE CHAPTER

A series of lectures on steel has been prepared by the executive committee of the Golden Gate chapter of the Society to be given each month. The subjects scheduled for presentation are as follows: "The Open Hearth Furnace," will be discussed by Howard S. Taylor, chief metallurgist with the Holt Manufacturing Company at the January meeting; "Recalescence and Decalescence Point of Steel," will be given by Dr. W. J. Crook, consulting metallurgist, Pacific Coast Steel Company at the February meeting; for the March meeting, O. H. Kottnauer, Standard Oil Company, will speak on "Alloy Steels and Their Uses"; the April meeting will be addressed by S. H. Edwards, Pacific Malleable Castings Company, who has chosen for his subject, "Hardening, Drawing and Annealing"; "Carburizing," will be the subject to be discussed at the May meeting by E. E. Jamison, president, Jamison Steel Company; A. B. Domonoske, associate professor of mechanical engineering at the University of California, will speak on "Testing Machines at the June meeting; "Temperature Measurements," will be the subject of H. E. Morse' address at the July meeting, and in August, J. H. Knapp, president of the James H. Knapp Company, will speak on "Heat Treating Furnaces." These lectures will be illustrated with lantern slides and charts.

HARTFORD CHAPTER

On Tuesday, December 9th, the Hartford chapter of the Society held a meeting at the Hartford Electric Light Company's Assembly Hall. "Modern Trend in Industrial Heating, Equipment and Operation," was the subject of a paper presented by F. J. Ryan and E. L. Wilson of the F. J. Ryan and Company, Philadelphia. This was a discussion of the principles of heat application, with particular reference to the problems of the steel treater and dealt with all of the usual fuels and methods of heat generation for this purpose, such as oil, gas and electricity, and showed the conditions under which each method develops its greatest efficiency or marked superiority. This paper was illustrated with lantern slides which showed the principles of construction of modern furnaces, as applied by the F. J. Ryan

company. An informal dinner was served at the University Club at 6:30 p. m., preceding the meeting.

INDIANAPOLIS CHAPTER

At the December 17th meeting of the Indianapolis chapter of the American Society for Steel Treating, E. T. Jackman, metallurgical engineer of the Firth-Sterling Steel Co., Chicago, presented an interesting paper on "Stainless Steel," outlining its history, production and use. Mr. Jackman stated that stainless steel is rapidly gaining a permanent place in industry, and anticipates that it will not be long before it is used for bridge work and steel construction as it does not rust, corrode or stain under weather conditions. An enthusiastic discussion followed this presentation. Dinner was served at 6:30 p. m. at the Y. M. C. A.

NEW YORK CHAPTER

The New York chapter of the American Society for Steel Treating held a meeting on Wednesday, December 17th, in the Assembly Rooms of the Merchants' Association of New York. The program for the evening was of unusual interest inasmuch as three recognized authorities in their particular fields, delivered addresses, after which followed a general discussion. L. H. Fry, metallurgical engineer of the Standard Steel Works Co., Burnham, Pa., discussed, "Steel for Rolling Stock, Particularly Locomotives and Cars." C. B. Bronson, assistant inspecting engineer of the New York Central Lines, who was associated in the past with the late Dr. Dudley, and is now carrying on the work started so many years ago on the production of quality rails, spoke on "Steel for Permanent Way, Particularly Rails and Bridges." The third address entitled, "General Requirements of the Railway," was given by James E. Howard, engineer-physicist of the Interstate Commerce Commission. His studies have enabled him to investigate the cause of many accidents ascribed to faulty metal. Dinner was served at the Post-Keller Restaurant at 6:30 p. m., preceding the meeting.

NORTH WEST CHAPTER

The North West chapter of the Society held a meeting on December 16th, at 8:00 p. m., in the Main Engineering Building of the University of Minnesota, at which time, J. M. Watson, metallurgical engineer of the Hupp Motor Car Corp., Detroit, presented a motion picture film entitled, "Modern Heat Treating Plant." The members of the local section of the American Society of Mechanical Engineers were invited to attend this meeting.

PHILADELPHIA CHAPTER

The members of the Philadelphia chapter of the Society were invited to attend a meeting at the Franklin Institute, at which time Francis F. Lucas, research laboratories of the American Telephone and Telegraph Company and Western Electric Company, New York City, presented an illustrated lecture on "High Power Metallography."

PITTSBURGH CHAPTER

The Pittsburgh chapter of the American Society for Steel Treating held its December meeting on the 2nd of the month in the Assembly Room of the Fort Pitt Hotel. Preceding the paper of the evening, the U. S. Bureau of Mines' motion picture, "The Story of the Automobile," was shown, which proved of considerable interest due to its depicting the fabrication and heat treatment of many of the important parts which enter into the construction of a Studebaker car at which plant the picture was taken. After the picture, Dr. Zay Jeffries, research bureau, Aluminum Company of America, Cleveland, who was the speaker of the evening, gave an interesting and instructive talk on "More About Steel," which was illustrated by charts and microphotographs. The theory of hardening and the various experiments used in proving it, were given in such a clear and concise manner that his audience followed him with profound interest. At the conclusion of his talk, many members availed themselves of the opportunity to have Dr. Jeffries explain how the theory would operate in specific problems.

RHODE ISLAND CHAPTER

On Wednesday, December 3rd, the Rhode Island chapter of the American Society for Steel Treating held a meeting at the rooms of the Providence Engineering Society. N. B. Hoffman, chemist and metallurgist, Colonial Steel Co., Pittsburgh, addressed the members on the subject, "An Illustrated Explanation of the Commonly Used Metallurgical Terms." A lively discussion followed this presentation.

The chapter held their December meeting on the 19th of the month, at which time, V. E. Hillman, director of research with the Crompton and Knowles Loom Works, Worcester, Mass., gave an illustrated address entitled, "The Evolution of the Blast Furnace and the Manufacture of Pig Iron from Iron Ore." Mr. Hillman, being an authority on this subject, gave a very capable presentation.

ROCKFORD CHAPTER

The Rockford chapter of the American Society for Steel Treating celebrated its third anniversary on December 12th with a well-attended dinner and meeting at the Nelson Hotel. The meeting was opened by Chairman Cotta, who, after a brief business session, turned the meeting over to the program committee in charge of O. T. Muehlemeyer. Mr. Muehlemeyer gave an outline of the steady, healthy growth of the chapter. The speaker of the evening, F. A. Hanson of the Industrial Electric Heating Apparatus Company, gave a very interesting talk on heating equipment.

The November meeting of the chapter was held on the 20th and was addressed by A. H. d'Arcambal of the Pratt and Whitney Company. His talk was well illustrated by lantern slides and an exhibition of small tools manufactured by the Pratt and Whitney Company. This meeting was well attended.

SCHENECTADY CHAPTER

On December 16th, the Schenectady chapter of the Society held a meeting in the Rose Room of the 20th Century Lunch Room, at which time, G. R. Brophy, metallurgist with the General Electric Company, addressed the chapter on "Shop Metallography." Dinner was served at 6:30 p. m.

SPRINGFIELD CHAPTER

The regular monthly meeting of the Springfield chapter of the Society was held on December 16th in the Chamber of Commerce Rooms. Hugh R. Corse, sales manager, Lumen Bearings Co., Buffalo, N. Y., gave an illustrated talk entitled, "Non-Ferrous Alloys." The regular get-together dinner was served at the Highland Hotel at 6:30 p. m.

SYRACUSE CHAPTER

The December meeting of the Syracuse chapter of the American Society for Steel Treating was held on the 15th of the month in the Hiawatha Room of the Onondaga Hotel, at which time John D. Cutter, vice-president of the Climax Molybdenum Co., New York, spoke on "The Advantages of Molybdenum in Steel." The meeting was well attended and an interesting discussion followed this presentation. Dinner was served at the University Club prior to the meeting.

TORONTO CHAPTER

The third lecture of the series which is being conducted by the chapter, was given by Prof. O. W. Ellis, on Friday, November 28th. It was entitled, "Metallurgy of Iron and Steel." New officers for this chapter have recently been elected. They are as follows: chairman, W. J. Blair; secretary, M. V. Willard, and treasurer, Prof. O. W. Ellis.

TRI CITY CHAPTER

The Tri City chapter of the American Society for Steel Treating held a meeting on Thursday, December 18th, at the Davenport Chamber of Commerce, at which time, J. M. Watson, metallurgical engineer, Hupp Motor Car Corp., Detroit, presented a paper entitled, "The Heat Treatment of Automobile Parts." This was illustrated by a motion picture, showing the heat treating operations at the new heat treatment plant of the Hupp Motor Car Corp. Dinner was served at 6:45 p. m. preceding the meeting.

WORCESTER CHAPTER

The Worcester chapter of the American Society for Steel Treating held a joint meeting with the local chapter of the American Society of Mechanical Engineers on Thursday, December 11th, in the Assembly Hall of the Amer-

ican Steel and Wire Company. Supper was served at 6:30 p. m. in the North Works Assembly Hall of the American Steel and Wire Company, at which about sixty-five members of both societies were served. C. R. Pafenbach of the Simonds Saw and Steel Co. was the speaker of the evening, and gave a most interesting talk on "High Speed Steel." He brought out the fact that the process of hardening high speed steel was really developed before the steel itself, as at present used, was perfected, it being applied by Taylor and White to self-hardening steel in 1900. The manufacture of high speed steel, Mr. Pafenbach said, is little different from ordinary crucible or electric furnace processes except that more care is required in certain operations. He emphasized the fact that good raw material is necessary to the production of a high grade steel. The electric furnace when first introduced got a bad name due to the fact that the manufacturers were apt to use inferior materials in the composition of the steel, believing that by some strange alchemy the "electric" furnace would transform it into a good product. Now that this idea has passed and good raw materials are used, the electric furnace is producing a high grade steel. In the hardening of high speed steel, Mr. Pafenbach said that the temperatures used were dependent of the physical characteristics of the tool as well as the work to which the tool was to be put. In general he recommended hardening at as high a temperature as practicable and adjusting the drawing temperature in accordance with the hardening temperature; a tool hardened at 2300 degrees Fahr. should receive a high draw from 950 to 1150 degrees Fahr., but if hardened at a lower temperature the draw should be considerably lower. Unless the tool is to be subjected to shock in its use, or there are fine edges and projections which will not stand the extreme temperatures, the high heat and high draw were recommended. A lively discussion followed Mr. Pafenbach's remarks, proving that although the subject has been covered thoroughly by many speakers and articles, it is still of much interest to the members.

(*Continued from Page 132*)

show up defects in steel bars? If so, how does it compare with the regular pickling processes?

QUESTION NO. 139. ***What is fibre, as related to forgings?***

QUESTION NO. 140. ***Can fibre be removed by heat treatment? How and to what extent?***

QUESTION NO. 141. ***Does fibre exist in castings which have been subjected to mechanical working?***

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

TOOL HARDENER would like position in or around vicinity of New York. Has had 11 years' experience. Is able to give A No. 1 references. Address 12-5.

CHEMIST desires position. Technical graduate. 20 years' experience in iron and steel business. Best of references. Address 12-10.

AN OPPORTUNITY to return to the steel game is desired by young man, age 25. 2 years heat treating and inspection on alloy steels, followed by 3½ years in telephone industry, with unusually varied experience and all around training in inspection planning, training, investigation and supervision and methods of engineering. Technical graduate. Married. Has handled 20 men on heat treating and has obtained results in 5 supervisory positions. Plans to develop eventually into sales organization. Now available. Location unimportant. Address 11-35.

CHEMIST, METALLURGIST, INSPECTOR, with 12 years' experience in open hearth, rolling mill and laboratory, wants to make permanent connection, where ability and experience will lead to advancement. Familiar with high and low carbon steels. No restrictions as to district. Address 11-45.

FOREMAN TOOL HARDENER OR HEAT TREATER wishes an opportunity to demonstrate his ability. Will consider position as assistant or anything. Formerly in charge of small heat-treating and hardening department. Six years' experience covering chemical analysis, metallography, physical testing, hardening of tool steels, high speed steel and drop forge dies. Expert hardener and can investigate tool troubles. Address 12-20.

METALLURGIST with wide experience in ferrous and non-ferrous (alloy) metallurgy and exceptional technical qualifications is desirous of opportunity to organize or control research department in ferrous or non-ferrous (alloy) metallurgical plant of department of metallurgy or physical metallurgy (either as professor or associate professor) in university. Address 1-25.

PRACTICAL HARDENER desires position. Has had 6 years' experience. Also has thorough knowledge of metallography and capable of performing microscopic work. Has general knowledge of ferrous and non-ferrous analysis. At present supervisor of heat treating department. Best of references furnished. Salary nominal. Address 1-10.

POSITIONS WANTED

TOOL HARDENER AND HEAT TREATER desires position. 12 years' practical experience covering all phases of heat treating. Fully capable of taking charge of hardening department. Eastern location preferred, but will go anywhere. Address 11-50.

POSITIONS OPEN

WANTED tool steel salesman for Detroit territory by one of oldest tool steel firms in business. One acquainted with treating tool steel desired. Very good opportunity. Salary and commission basis. In reply give education, training, experience, married or single. Address 12-15.

BEARINGS MANUFACTURER needs experienced man skilled in annealing and preliminary heat treatment and cold drawing of bearing steels. State full particulars and experience. Address 1-30.

HIGH GRADE STEEL MANUFACTURER contemplates installing department for cold finishing wire, small size bars and ribbon steel. Interested in man competent to install and operate department. State full experience. Address 1-35.

WANTED young man as assistant to metallurgist, for experimental department of steel mill making tool and alloy steels. Give full details in first letter, including wages expected and why applicant thinks he can fill the job. Address 1-5.

WANTED: Representatives wanted with heat treating experience in the following territories: St. Louis; Birmingham, Alabama; Texas; San Francisco; Pittsburgh; Tulsa, Oklahoma; Buffalo and Cincinnati. Must be capable of earning $5000.00 per year. Address 1-20.

LARGE AUTOMOBILE manufacturer located in Cleveland has position open for assistant metallurgist capable of handling microscopic work and investigations. Excellent opportunity for the right individual. If interested, write at once. Address 1-40.

WANTED

FOR SALE—One Stewart gas fired vertical muffle furnace, practically new. Pratt and Whitney Company, Small Tool Works, Hartford, Conn.

FOR SALE—Bausch and Lomb metallographic microscope. First class condition and ideal for a student. Vertical type. Will sell at a sacrifice. Address 1-15.

Items of Interest

LOUIS E. ZURBACH, long associated with Wetherell Brothers Company of Cambridge, Mass., announces the incorporation of the L. E. Zurbach Steel Company, with office and warehouse at 145 Oliver Street, Boston, where he will be pleased to serve his patrons.

Mr. Zurbach has been a very active member of the American Society for Steel Treating, having been chapter chairman of the Exhibit Committee for the Boston Convention last year.

L. E. ZURBACH

Accidents occurring at metallurgical plants in the United States in 1923 resulted in the death of 58 men and the injury of 8,476 others, according to statistics compiled by the Department of the Interior, through the Bureau of Mines. The figures constitute a fatality rate of 0.96 and an injury rate of 141 per thousand full-time (300 day) workers. For 1922 the corresponding rates were 0.98 and 145 respectively.

Reports received by the Bureau of Mines from companies operating ore-dressing plants and smelters in 1923 indicated a continuance of the upward trend, begun in 1922, from the low record of 1921, in volume of work done by the industry. At ore-dressing plants the number of man-shifts of work reported was 92 per cent above 1921 and 40 per cent above 1922; it was only 8 per cent below 1920, the most recent "normal" year. The reports for smelting plants showed an increase of 88 per cent in the number of shifts worked as compared with 1921, and an increase of 28 per cent as compared with 1922; the number was within 12 per cent of the number of shifts worked in 1920. The average working time at ore-dressing plants was 300 days per man; at smelters, 357 days; the former figure has not been exceeded since the war-year 1918, when the average operating time was 310 days per man; the latter figure for smelting plants is the highest on record. The nearest ap-

S. M. Co. Brinell Machine

This machine applies a pressure of 3,000 Kilos to a 10 mm. ball and gives results in Brinell numerals, the international standard for indicating hardness of metals.

The Pressure is applied quickly and evenly, and a patented feature prevents the leakage of the hydraulic fluid.

Pieces from $\frac{3}{16}$ inch to 12 inches may be accommodated. The anvil is adjustable to irregular shaped pieces.

The Standard Machine Adopted by

American Can Co.
American Machine & Mfg. Co.
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Canadian Fairbanks Morse Co.
Carbon Steel Co.
Carnegie Steel Co.
Chicago Pneumatic Tool Co.
Columbia Steel & Shafting Co.
Curtis Aeroplane & Motor Co.
Dayton Engineering Laboratories
Dominion Steel & Foundry Co., Ltd.
Eagle Pitcher Lead Co.
Firth-Sterling Steel Co.
Henry Ford & Son, Inc.
General Electric Co.
Hughes Tool Co.
Latrobe Electric Steel Co.
Lincoln Motor Co.
Maxwell Motor Co.
McMyler Interstate Co.
Nash Motors Co.
Oliver Chilled Plow Works
Parish & Pool Co.
Piston Ring Co.
Pittsburgh Testing Laboratory
Pollack Steel Co.
Premier Motor Corp.
Railway Steel Spring Co.
Standard Foundry Co
Standard Steel Car Co.
Standard Steel Spring Co.
Studebaker Corp.
Underwriters' Laboratories
Union Switch & Signal Co.
Vanadium Alloys Steel Co.
Westinghouse Electric & Mfg. Co.

And Many Others

Send for descriptive bulletin 103

SCIENTIFIC MATERIALS COMPANY

"Everything for the Laboratory"

PITTSBURGH, PA.

proach to the record for smelters in 1923 was that for 1913, when 355 workdays per man was recorded. The increase in volume of work was general throughout the country, and was shared by nearly all States.

The reports showed a total of 54,418 men employed during 1923 at ore-dressing plants, smelters, and auxiliary works; the men performed 18,047,774 days of labor, an average of 332 days per man. The number of shifts worked was 4,245,456 in excess of the number reported for 1922.

The accident rates in the metallurgical industries for 1923 may be segregated as follows: For mills, the rates per thousand full-time workers were 1.55 killed and 168 injured; for smelters, 0.64 killed and 131 injured; for auxiliary work, 0.94 killed and 132 injured.

Of the 8,534 accidents during the year, 0.68 per cent were fatal, 0.01 per cent resulted in permanent total disability, 1.91 per cent resulted in permanent partial disability, 26.42 per cent caused temporary disability for more than 14 days, and 70.98 per cent caused temporary disability for more than the remainder of the shift, but not exceeding 14 days.

We have received word that copies of Professor A. E. White's paper dealing with the subject of Industrial Electric Heating may be supplied at the price of 50 cents per copy, to those desiring this article, by applying to Colin G. Fink, secretary of the American Electrochemical Society, in care of Columbia University, New York City.

G. C. McCormick, formerly at the Syracuse office of the Halcomb Steel Company, has been transferred to the Boston office of the Crucible Steel Company of America in a sales capacity.

A new bulletin describing the Republic Coal Meter has just been published by the Republic Flow Meters Co., Chicago. This bulletin is well illustrated and all operations are fully described. It is reported by this company that this is the first instrument of this type which has ever been put on the market in this country.

Al Grinnell, Detroit representative for the General Alloys Company, has reached the pinnacle of fame in golfdom as shown by the following dispatch:

> Detroit, Dec. 3.—A. L. Grinnell of this city accomplished what has been considered the impossible by the champion golfers of this country when he made the thirteenth hole in one at the Meadowbrook Country Club. Mr. Grinnell's spectacular shot places his name on the club's "Hole in One Club," which at present contains but two other members who have accomplished this feat.

This news will be happily received by Mr. Grinnell's numerous friends, as it pertains to his success on the 13th hole, while it has been noted for some time that Al's great accomplishments have been the reputation he has maintained for accomplishing his best results on the 19th hole.

SIMONDS STEEL

CRUCIBLE ELECTRIC

For those users who demand the most
from their finished steel product

PERMANENT MAGNET STEELS
HIGH SPEED
BULLET PROOF STEEL for ARMORED CARS
VALVE STEELS
CHISEL STEELS
CARBON AND ALLOY TOOL STEELS
SPECIAL STEELS

BARS SHEETS BILLETS

SIMONDS SAW and STEEL CO.
STEEL MILLS
Lockport, N. Y.

A. M. Diehl has just organized his own company, specializing in the distribution of tool steel and steel specialties, and importing the famous Dannemora Tool Steels. His office is located at Front and Smith Streets, Cincinnati, the name of the company being the Diehl Steel Company.

G. V. Nightingale, formerly sales engineer with the Celite Products Co., Chicago, resigned on November first to become associated with the Republic Flow Meters of Chicago, as sales engineer in the Philadelphia office in charge of pyrometer sales.

The United States Civil Service Commission announces the following open competitive examination for the positions of fuel engineer, associate fuel engineer, assistant fuel engineer.

Receipt of applications for fuel engineer, associate fuel engineer, and assistant fuel engineer will close February 3. The examinations are to fill vacancies in the Bureau of Mines, Department of the Interior at entrance salaries of $3,800, $3,000 and $2,400 a year, respectively. Advancement in pay may be made without change in assignment up to $5,000 a year for fuel engineer, up to $3,600 a year for associate fuel engineer, and up to $3,000 a year for assistant fuel engineer.

Appointees must be able to conduct, under general direction, laboratory and field fuel investigations, especially in combustion, furnace design, smoke prevention, heat transmission, efficiency of fuel using devices, and must also be able to prepare concise and intelligent reports thereon. They will also be required to assist in tests of boiler and other furnaces and of auxiliary equipment affecting efficiency in the use of fuels, and in investigations of fuel burning methods and machinery, inspecting and sampling of fuel, and compiling of data.

Competitors will not be required to report for examination at any place, but will be rated on their education, training, experience, and fitness; and an essay, thesis, publication or report to be filed with the application.

Full information and application blanks may be obtained from the United States Civil Service Commission, Washington, D. C., or the secretary of the board of U. S. civil service examiners at the post office or custom house in any city.

The Kilborn and Bishop Co., New Haven, Conn., announces a consolidation with the Bay State Forge Company, Springfield, Mass. The business will be carried on in New Haven under the name of the Kilborn and Bishop Company.

J. A. Succop, formerly metallurgical engineer with the Heppenstall Forge and Knife Co., Pittsburgh, has accepted a position with the Colonial Steel Company and will be located at Philadelphia in charge of their warehouse and sales.